THREE-COLOUR PHOTOGRAPHY:

WITH SPECIAL REFERENCE TO

THREE-COLOUR PRINTING

AND SIMILAR PROCESSES

"THE WEDDING MORNING."

Negatives made with Cooke Process Lens on Penrose's Panchromatic Plates, with a Penrose Colour Camera. Printed with Penrose's Standard Chromatic Inks.

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AND SIMILAR PROCESSES.

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AUTHOR'S PREFACE.

THE first German Edition of this book appeared in 1897, and it was the first work published which entered into all details concerning three-colour photography Based upon the laws of colour mixtures, general rules of colour decomposition by photographic means are discussed, and the composition of printing inks ascertained for the purpose of enabling a satisfactory recomposition of colour to be effected

The very pleasing reception of the book necessitated a second edition in 1904 and a third edition in 1912 The work was then completely revised and brought up to date Special attention was given to the practical part, especially that relating to photographic colour decomposition

As colour filters must be adjusted to suit the sensitiveness of each particular plate, and as the numerous dry plates which are commercially obtainable, show great variations in their colour sensitiveness, filter recipes would be of little value and are not, therefore, given Colour scales attached to this book should, however, enable everyone to adjust his own filters

In writing this book I have been guided by the conviction that a simple and easily workable process serves the practical man better than a complicated process which may be theoretically more correct Simplification has been my aim throughout the work

The often-expressed wish for an English edition has been met by Mr H O Klein, F R P S , who has undertaken the difficult task of its preparation This fact is flattering to me not only because Mr Klein has mastered the theory and practice of three-colour photography in all its details, but also by reason of his being intimately acquainted with its literature, and his name, therefore, offers the best guarantee for a perfect and faithful translation

A VON HUBL.

Vienna.

PREFACE OF THE TRANSLATOR.

THIS work has been largely rewritten since the first English edition appeared in 1904.

During the ten years which have since elapsed, important additions have been made to our knowledge of colour sensitizing, whilst complicated processes have been simplified, and have become the foundations on which prosperous businesses have been established.

Three-Colour Process Work, once a monopoly of one or two firms, which are now long extinct, has become the property of all. This is chiefly due to the influence of standard works on Colour Photography, of which Hubl's "Three-Colour Photography," is a classical example, and to the efforts of numerous excellent technical journals in disseminating knowledge of the processes involved.

I wish to tender thanks to the editors of these journals for kind and illuminating criticism of the translation of the first edition, and also to Mr. W Gamble, F.R.P.S., who not only revised the first and second editions, but in many ways assisted me by his advice and valuable suggestions. I am also deeply indebted to Baron Von Hubl, under whose personal supervision the supplements to this book were printed, and whose generous attitude as author made the publication of this English edition possible.

Westcliff-on-Sea. H. O. KLEIN.

April, 1915.

INTRODUCTION.

ALL pictorial representation endeavours to secure the nearest possible approach to nature, for the absence of which it is supposed to compensate.

As it is not always possible to accomplish this by mere outline drawing, shading and colour are added to increase the illusion of body, and to add life and truth to our representation.

To appreciate the beauty of an outline or a shaded monochrome drawing requires a certain amount of artistic perception, but a harmonious colour scheme will always appeal to the general public, who prefer the worst colour print to the most exquisite photogravure, and who compel publishers to tint woodcuts and copper engravings to ensure a ready market

Colour certainly intensifies our illusion, just as plastic representation does, and who is more likely to regret the absence of colour than the photographer, who has the daily opportunity of comparing the magnificent colour picture on the focussing screen with his monochrome copy? To solve the problem of colour photography has been the keen desire of many, and experiments in this direction may be divided into two sections

1) The production of sensitive surfaces, capable of assuming the colour of the light falling upon them, (2) photographic analysis of colour and synthesis by means of dyes or pigments

The first method may be termed the direct, the second the indirect process of colour photography.

The first experiments directed towards a solution of the problem of direct colour reproduction were based upon the property silver-sub-chloride has of acquiring the colour of the light projected upon it, and they date back to the time of BECQUEREL, SEEBECK, POITEVIN, and several others

ZENKER in 1868 explained the production of these colours by a theory of stationary light waves, which theory received full confirmation by LIPPMANN, who in 1891 conducted a series of experiments proving the existence of stationary light waves and interference colours

Although received with unbounded enthusiasm throughout the whole scientific world, Lippmann's process proved of no practical value, owing to the great difficulties of procuring perfect results

The most noteworthy exponents of the process are E. VALENTA, LUMIÈRE, KRONE, DR NEUHAUS and DR LEHMANN

According to WIENER the colours of direct photochromes are produced either by interference or by actual body colours Interference colours are induced by standing light waves in Becquerel's silver-chloride plates, and in the bromide of silver film when resting upon a mercury mirror, as in the case of the Lippmann process, but body colours are formed in papers coated with silver-sub-chloride, as used by SEEBECK and POITEVIN

The formation of body colours is explained by WIENER in the following theory —

A light-sensitive surface can only be influenced by rays of light, which the substance absorbs, red rays causing no effect upon a red-coloured body, yellow and green rays no effect upon a yellow or green-coloured body

A light-sensitive substance, capable of acquiring colours due to the action of coloured light, will under the influence of red, yellow or blue light continue to change colour until a permanent red, yellow or blue coloration is reached Silver-sub-chloride is one of these substances,

and the production of coloured photographic pictures on paper coated with it is thereby explained

Papers coated with a mixture of fugitive coal-tar dyes give, after exposure under coloured transparencies, coloured prints, due to the bleaching influence of light

The process based upon it is called the *Bleaching-out process*, and was brought to its present state of perfection by the labours of Dr Neuhaus, H Worel, J Szczepanik, Dr Limmer and, in particular, Dr J H Smith, the inventor of the *Utocolor Paper*

This paper, although not quite perfect for practical requirements, surpasses any other bleaching-out paper and it is probable that in the future coloured transparencies, produced in the camera, will be printed on paper, which may be a modification of *Utocolor Paper*

The idea of indirect colour photography, now forty years old, is evolved from the theory of trichromatic analysis, which teaches us that all colour sensations can be stimulated by three colours, yellow, red and blue and their mixtures Every coloured object may, therefore, be reproduced in its colours by a method called " Three-colour photography "

Until quite recently only one practical and useful way of three-colour photography was known, and this method will be first discussed

The object is photographed three times, and in such a way that the colours are analysed into three components, each one producing a negative From such negatives prints are made in yellow, red and blue colours, which are superimposed, thereby synthetizing the colours of the object.

The production of the negatives is always exactly the same, but the process of producing the component pictures and that of combining same may widely differ

The coloured prints may be made by the carbon process or one similar to it , they may be on glass or celluloid support , they may be transferred and superimposed on paper , or blocks can be made from the negatives and then printed in the letterpress manner in three colours, one over

the other, in perfect register The carbon process served well in the earliest experiments of DUCOS DU HAURON, because it was the only process, at that time, capable of giving prints in any required colour, but it has also been lately made use of by the New Photographic Co, of Berlin, for their *Rotary process* of colour photography

Photographic three-colour printing, dating back to 1865, was perfected chiefly by DR H. W VOGEL and DR E ALBERT, who introduced this process to the practical illustrator This process is in universal use to-day, due to the great perfection of the half-tone process

Photography is not absolutely required for the production of the three plates, and it is theoretically of no importance whether the three component pictures are produced by manual labour or by pure photography

In practical work, however, the production of the plates by an artist presents insurmountable difficulties, because the most experienced chromo-litho artist is not able to judge the effect of a mixture of three such very different colours as the primaries

Three-colour printing with plates produced by an artist is theoretically possible, but useless in practice To avoid the somewhat laborious printing from blocks, SANGER SHEPHERD introduced a process in which gelatinized plates, after printing, are soaked in yellow, red or blue dyes, which are absorbed by the image portions only The plates are pressed into contact with gelatinized paper, which takes up the dye, resulting in a picture in colours A modification of this process is called *Pinatype.*

Instead of superimposing pigment pictures, we can also compose our picture by optical means, which idea is the basis of polychrome projections and of the *Photochromoscope* This idea was first suggested by DUCOS DU HAURON and made practical use of by LEON VIDAL, IVES, SCOTT and DR. MIETHE The three negatives are printed on ordinary chloride or bromide of silver plates, the transparencies are backed with a yellow, red and a blue glass

and are projected on a white screen by means of a triunial lantern Assuming that the colours of the glasses correspond to theoretical requirements, the three projected and superimposed lights will result in white light, and when the transparencies are backed with the glasses and are projected, a picture in the colours of the original will be the result

In the IVES *Photochromoscope* the three positives are also backed with coloured glasses , they are not, however, projected by means of lanterns, but superimposed and reflected to the eye by a system of mirrors formed by supplementary light filters

The colours of the glasses of the *Photochromoscope* and of those required for projection by a triunial lantern always remain the same, once measured and found to be theoretically correct, but the colours for previously mentioned processes sometimes require special adjustments Moreover, the Photochromoscope does not furnish us with material pictures, and for this reason remains of minor practical importance

A very original idea, suggested by DUCOS DU HAURON in 1869, was made use of by PROF JOLY, of Dublin, in 1894

JOLY used glass plates, ruled with very thin, transparent lines of red, green and blue colour, about 10 lines per mm The colour of the lines is repeated in the order given, and the plate appears by transmitted light of a light grey colour

If such a plate is pressed during exposure into contact with a photographic plate, sensitive to all colours, red rays reflected from the original can only pass through the red lines, green rays only through green lines, and blue only through blue lines, and these affect the photographic plate, giving a negative of the three component images upon one plate If a transparency is made from this negative, and viewed in contact with a similar screen to that used during the exposure, we obtain, when the two

plates are in perfect register, a picture of the object in natural colours.

Little use was made of this process, because the manufacture of the screen plates is extremely difficult

A remarkable solution of the problem of three-colour photography was accomplished by the well-known Bros LUMIÈRE, of Lyons, by the introduction of their *Autochrome* plates, which are now commercially obtainable and give, after exposure in the camera and treatment similar to that of any ordinary negative, perfect transparencies in natural colours The practical man, however, requires prints on paper and it is to be hoped that the *Bleaching-out process* will be made practical for paper reproduction of the beautiful *Autochromes**

The author only intends to deal in this work with methods of three-colour photography which require three negatives, and which furnish material colour pictures

The practical part of such methods may be divided into The analysis of the colours, and the production and superposition of the component images

The problem of analysis may be considered as solved, because the sensitiveness of photographic plates and the absorption of light filters is now under complete control, but the solution of the second, dealing with the production of the printing plates, is far from being satisfactory In three-colour printing, retouching is still required, although the mechanical printing on the press ensures uniformity of edition In all other processes the results are governed by chance, the methods are quite unreliable and cannot be considered as satisfactory from a practical standpoint

* Screen plate processes based on similar principles have lately been put on the market under the names of the Paget and the Dufay colour processes —*Trans*

PART I

LIGHT AND COLOUR.

A COLOURED LIGHT

IT is generally assumed that the phenomenon which we term "light" is induced by vibrations of the luminiferous ether, an extremely subtle medium, supposed to pervade all space, and to permeate all matter

If this ether is undisturbed, we have the sensation of darkness, if vibrated, that of light A body, in the state of incandescence is likewise in a state of violent molecular vibration, and is capable of exciting ether waves, which are propagated in all directions, and with enormous rapidity impinge upon the human retina, producing the sensation of light

The vibrations of an incandescent body are imparted to the ether in a way similar to that of the sound waves of air If vibrations of air impinge upon our ear we are aware of the sensation of sound, if those of the ether reach our optic nerve, we receive an impression of light Moreover, the wave motion of the ether is induced by perpendicular stationary oscillations, which are transmitted from particle to particle

Bodies show different behaviour towards the advancing ether waves, some offer no resistance to their advance—they are transparent bodies—others cause reflection, and, finally, most bodies offer more or less resistance—they are opaque or translucent, and absorb light entirely or partially

If a body in motion meets another resisting body, the velocity of the first may be transformed into heat, *e g*, the example of the hammer and anvil

If one of the two bodies does not possess sufficient resisting power, a total breaking up or a slight alteration of its molecular structure may be the result The change in the molecular structure of a substance is equivalent to a chemical reaction, and the substance is then termed "light sensitive"

In the case of wave motions we have to consider two characteristic magnitudes, the path of the oscillating wave during one oscillation, or the "Amplitude," and the time required for it—the "Undulation period" The latter may be expressed by the number of oscillations per second

The distance from wave crest to wave crest is termed "wave length," and theory teaches us that the wave length is inversely proportional to the undulation period

The greater the distance of the hammer from the anvil, the more powerful will be the effect, accordingly the greater the stroke of the ether particles the greater their amplitude, the more intense their effect upon the retina, the brighter the sensation of light and their consequent chemical action The intensity of light is, therefore, directly proportional to the "amplitude" of the ether waves

The slight tap of a hammer may deform a piece of lead, but makes no impression upon steel, however often repeated Similarly, the ether waves of small amplitude may decompose the bromide of silver of our dry plates, but have no effect upon the iodide of silver of the wet plate, however long the exposure may be, this explaining the well-known fact that a slow plate cannot be fully exposed when the illumination of the original is bad

The number of vibrations and the wave length determine the keynote in the case of sound, and in that of light the colour sensation.

The vibration numbers of coloured light have been measured and found to be 400 billions per second for red, increasing in number for yellow, green and blue, and finally reaching 750 billions per second in the case of violet colour sensations.

The wave lengths are inversely proportional to the number of undulations and vary between $\frac{750}{1\,000,000}$ to $\frac{400}{1\,000,000}$ part of a millimetre

1 The Spectrum.

The most important source of light is the sun, the light of which we call "white," whilst every other quantitatively different sensation is termed "coloured"

When sunlight passes through a glass prism it is decomposed, and on a suitably placed white screen the brilliantly coloured spectrum will be visible Countless variations from red to yellow, and from green to blue and violet, are represented in the spectrum, and it would be idle to talk of counting the spectral colours

We conclude, therefore, that the sensation of "white" is caused by the simultaneous action of ether waves of different wave lengths upon our retina, and further, that white light is composed of all the coloured rays visible in the spectrum

The solar spectrum is divided by numerous fine lines, known as "Frauenhofer" lines, the most distinct of which have been named with alphabetic letters

These lines form a very convenient and reliable means of locating certain colours in the spectrum, and spectral colours, or light of a certain wave length may be defined by reference to adjoining spectral lines

Fig 1 shows the position of the most important lines in relation to the spectral colours The numbered lines state the corresponding wave lengths in a millionth part of a millimetre, a magnitude expressed by $\mu\mu$ A length of this magnitude is known as "Angstrom unit"

The intervals between the numbered lines are narrow in the red end and increase towards the violet end of the spectrum We conclude, therefore, that the red rays in the spectrum are confined to a more limited area than the blue violet The visible red extends from the extreme limit of the spectrum to line C ; it is a red with a yellowish

hue From C to D the red becomes orange, melting into a pure yellow close to D The pure yellow is represented by a very narrow band, then becomes yellow-green, which between E and b is deeper green in colour, pure green after C, and approaching F is a blue green, named by HELMHOLTZ Cyan Blue.

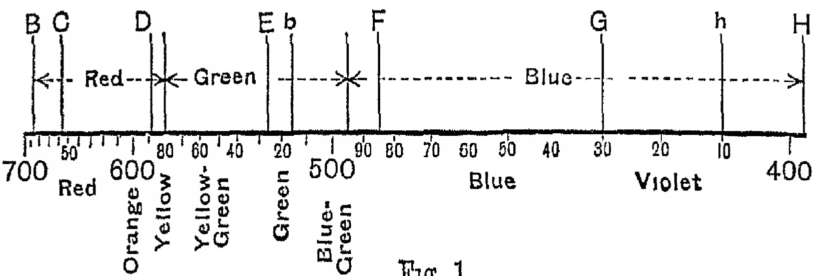

Fig. 1.

This blue green is like that seen in mountain lakes and on glaciers Beyond F the blue loses its greenish hue and gradually develops into a violet near the line G

The pure blue is generally called indigo, but is really more like ultramarine. From G to the end of the visible spectrum a blue violet of low intensity is visible According to KONIG and DIETERICI ("Helmholtz Physiological Optics") the red up to line C only differs in luminosity and not in hue, which also holds good in the case of the violet, beginning at the line C, and terminating near H

Actual differences in the hues of spectral colours can only be found between the lines C and G. Red violet or purple represented by certain dyes of the Eosine group is completely missing, but can be formed by superposition of the red and violet end of the spectrum The interposition of this colour ensures a complete and repeating colour circle

There is another method of producing the spectrum, and this by means of a diffraction grating A diffraction grating consists of a glass plate which is engraved with extremely fine parallel lines. The spectrum produced by gratings shows the same order of spectral colours as the prismatic spectrum, but with considerable differences in

luminosity and distribution Fig 2 shows the wave length scale of the diffraction spectrum, which is notable for its simplicity, and is for many purposes preferable to that of the prism spectrum Moreover, as the material producing the spectra has no influence upon the colour distribution, the diffraction spectra are considered "normal spectra" by the scientific investigator

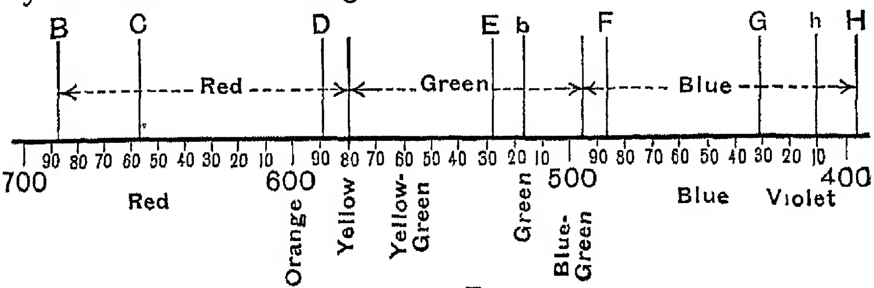

Fig. 2.

We find the red most extended, the green occupying about the same space as in the prismatic spectrum, and the blue-violet considerably less Yellow is near the centre, and like blue-green confined to a narrow band

For ordinary practical work the prism is generally in use, partly on account of the delicacy of the gratings, their relative high cost, and partly on account of the greater luminosity of the prismatic spectra.

As mentioned before, the colours of the spectrum are equivalent to ether undulations of a frequency from 400-700 billions per second Various experiments proved, however, the existence of ether waves of greater and minor undulation periods, and the existence of an invisible spectrum on either side of the visible, known as "infra red" and "ultra violet"

The last-named especially, though not visible, is extremely active chemically The photographic plate exposed to the spectrum records numerous bands in the infra red and ultra violet The reason why infra red is invisible is found in the absorption of those rays by aqueous substances, which screen our retina Ultra violet is invisible, because our organs of sight are very defective, and are incapable of being excited by waves of such high frequency as those producing ultra violet light.

The distribution of colours is very unequal in prismatic and diffraction spectra, red, green and blue show broad bands, but the intermediate colours occupy narrow spaces The extreme violet and red are of such low luminosity as to be hardly visible A short spectrum appears almost red, green and blue only, and if we had to divide the three we should probably split the spectrum at wave length $\lambda = 580$ and $\lambda = 495$

Figs I and II show the spectrum divided into three parts, red, green and blue Although the colour bands are not equal in size in both spectra the rays of light forming the colours are equal in quantity, only distributed over larger or smaller areas

MONOCHROMATIC AND POLYCHROMATIC LIGHT

By means of collecting lenses, all the colours of the spectrum can be superimposed, the resulting mixture of coloured light forming white light By superimposition of parts of the spectrum colours only, omitting certain bands, we obtain coloured light mixtures of a uniform tint, which in no way indicate their composition

We have, therefore, to differentiate between monochromatic and polychromatic lights, between light of one wave length only or light of a mixture of different wave lengths We, therefore, also speak of primary pigment colours and colour mixtures White light is always polychromatic, *i e*, a mixture of many coloured lights

As already mentioned, the superposition of parts of the spectrum only, omitting certain sections, gives uniformly coloured light mixtures, yet by suitable choice of two spectral colours only white light may be recomposed Such spectral colours are called "complementary"

Complementary colours are

Red and blue-green
Orange and greenish blue
Yellow and blue
Greenish yellow and violet

Every transition colour from red to greenish yellow is complementary to another between blue-green and violet

Pure spectral green is complementary to no other primary colour, but to mixtures of red and violet, called purple

On the basis of the above observations we may formulate the following definitions Every spectral colour is complementary to another colour, with which, when combined, white light can be formed

The wave lengths of such complementary lights have been ascertained, and are, for instance

Red of wave length 640 is complementary to green of wave length 495

Orange of wave length 590 is complementary to blue of wave length 485

Yellow of wave length 575 is complementary to blue of wave length 470

The measurements, however, are greatly influenced by the constitution of the individual human eye and vary with different observers, especially in the red and violet to the extent of 10 $\mu\mu$

V GRUNBERG ("Year Book of Photography," 1905) establishes the equation for wave lengths L and L^1 as

$$L^1 = 498 - \frac{424}{L - 559}$$

Experimental results have confirmed the accuracy of this equation

If we mix two coloured lights, which are closer to each other in the spectrum than their complementaries, we get coloured light, diluted with a certain amount of white light If we mix two coloured lights which are beyond their complementary boundaries, we also obtain a spectral colour of whitish hue If we mix the two ends of the spectrum, we obtain a purple, which is devoid of the full saturation of other spectral colours

We append a table taken from Helmholtz's "Physio-

logical Optics," showing at a glance the result of a mixture of two spectral colours

At the head of the horizontal and vertical columns are placed the pure colours, and at their intersections the resulting colour mixtures

	Violet	Indigo	Cyan Blue	Blue Green	Green	Greenish Yellow	Yellow
Red	Purple	D Pink	W Pink	White	W Yellow	Golden Yellow	Orange
Orange	D. Pink	W Pink	White.	W Yellow	Yellow	Yellow	
Yellow	W Pink	White	W Green	W Green	Yellowish Green		
Greenish Yellow	White	W Green	W Green	Green			
Green	W Blue	Water Blue	Blue Green				
Blue Green	Water Blue	Water Blue					
Cyan Blue	Indigo						

D—Dark W—Whitish or light

This table shows in how many different ways the same mixed colour may be obtained, for instance, yellow and violet give the same result as red and cyan blue, *i e*, whitish pink, and also that to ascertain the composition of a mixed colour the use of the spectroscope is absolutely necessary

As all possible colour sensations find representation in the spectral colours and the additional purple no new colour sensation can be created by admixture of more than two spectral colours, the larger the number of components in a colour mixture, the less saturated will be the mixed colour, due to heavy admixture with white If rays of any part of the spectrum reach our retina, we only perceive the sensation of one spectral colour or the additional purple

The resultant colour mixture, which is the less saturated, as the spectral band becomes broader, must be complementary to a colour mixture of the remaining spectrum band

Of considerable interest are mixtures of the light rays forming any one of the three spectral bands, which serve us as a roughly divided spectrum The rays of the red part give a mixing colour of wave length $\lambda = 610\ \mu\mu$

generally called vermilion, and complementary to a blue green which is obtained by mixing the remaining rays of the spectrum

The rays of the green part give a yellow green of wave length $\lambda = 540\ \mu\ \mu$, which is complementary to a mixture of the red and blue part of the spectrum, called purple

The rays of the blue part give a blue of wave length $\lambda = 465\ \mu\ \mu$, which is complementary to the mixture of red and green, called yellow It is immaterial whether the infra red or the ultra violet is included or not, because they are of too low a luminosity to affect other brilliant colours

It has further been proved that the composition of coloured lights has no influence upon the mixing results, as red and yellowish green combine to produce yellow, and the latter behaves in mixtures with other coloured light exactly as if it were pure spectral yellow, or a yellow obtained by addition of the rays of a complete spectral band.

When we perceive a colour certain properties peculiar to it are noticeable and they may be classified as follows The *hue* of the colour, the qualitative different colour sensations from black or white, and its *purity*, conditioned by the absence of admixture with white Transitions from the pure colour to mixtures with white or black, are called "tints" or "shades"

From a physical standpoint we differentiate between the *hue* of a colour, conditioned by its wave length, the *luminosity* or intensity, conditioned by the amplitude, and the *purity*, which depends upon the absence of rays of light which are likely to form with the colour the sensation of "white"

Referring to the luminosity of colours we have to remember that the "specific" luminosity of certain colours is not to be taken into consideration. Yellow light, for instance, appears very much brighter than blue light, and the term brightness or luminosity is often wrongly applied to colours mixed with white

2 The Theory of Colour Sensation

As already shown, light of physically very different composition can excite similar colour sensations Our eye cannot determine whether the impression of "white" is caused by the simultaneous action of all rays of the spectrum, or whether, for instance, only blue-green and red are present A mixture of vermilion red and blue excites exactly the same colour sensation as violet and yellow In this respect our eye differs greatly from our organs of hearing When struck by sound waves of differing undulation periods, although combined in a chord, we are capable of distinguishing the different notes Two chords, which are composed of different sounds, are never identical to our ear, but colour mixtures, however differently constituted may appear identical to our eye.

We can only find an explanation for this strange phenomenon in the supposition that our eye is susceptible only to a limited number of elementary sensations, and we therefore base our hypothetical theories of colour vision upon such an assumption

THE THEORY OF YOUNG-HELMHOLTZ

Thos Young's theory (1807), accepted by Helmholtz and Maxwell, is known as the Young-Helmholtz theory, and finds almost undivided favour with the majority of physicists. This theory assumes the presence of three kinds of light-sensitive nerve fibrils in the human eye, serving as the means of communication for the three primary colour sensations When excited they convey to our brain sensations of red, green or violet respectively

If all three nerve fibrils are excited simultaneously, and with same intensity, the sensation of white results, and when at rest that of black

Young selected as his fundamental colours red, green and violet Experiments, however, have shown that it is impossible to mix all other intermediate spectral colours by means of the three primaries in anything like full purity

If we mix, for instance, the red of the spectrum with the green of line E, we obtain a yellow similar in hue to spectral yellow, but greatly diluted with white If, however, a yellow-green is used, we obtain a very pure yellow, but when mixed with spectral violet a whitish blue is the result

It follows that the purity peculiar to spectral colours cannot be attained by mixing the three spectral primaries, and that we have to assume the existence of coloured lights of much greater purity than that of the spectral colours. We can only imagine such fundamental colours, because the spectral colours are the purest colours known to us Moreover, we can base our hypothesis on the assumption of their existence and explain the causation of the different colour sensations as follows —Every spectral colour is composed of all three fundamental colours, and the curves in Fig 3 represent the intensity of stimulus required to produce spectral colours The "ordinates" of curve R represent the intensity with which the red sensitive nerve fibrils are excited by the spectral colours As shown in the diagram the nerve fibrils are most intensely irritated by red orange, but yellow, green and blue also cause a stimulus Curves Y and V show the stimulus which the green and violet sensitive nerve fibrils receive by various spectral colours The curves represent, therefore, the proportions in which the fundamental colours are to be imagined to be mixed to produce the various spectral colours

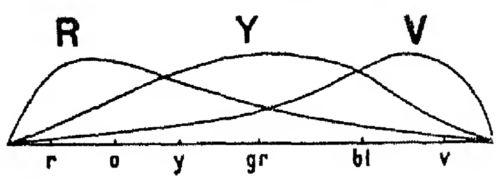

Fig 3.

We have to imagine the spectral red to consist of fundamental red, and a small proportion of fundamental green and violet

This mixture weakens the purity of the spectral red, which, compared with the fundamental red, must be considered of a distinctly whitish hue

The spectral yellow is most intense in its action upon the red and green sensitive fibrils, less upon the violet sensitive ones, and we assume it to be composed of equal quantities of fundamental red and green, with a slight admixture of fundamental violet, being, therefore, of a whitish hue.

In a similar manner the sensation of spectral green, blue, or violet is explained, but these colours must always be considered less pure than the fundamental colours, which cause a stimulus to one order of nerve fibrils only

The above curves, however, differ considerably from those representing actual mixing results, and according to Helmholtz the fundamental colours are present in equal proportion in all spectral colours, and must be considered of extreme purity when compared with spectral colours

Helmholtz states that the choice of the three spectral colours may be arbitrary, because any triad may be selected in the spectrum for the recomposition of white light

Young's choice fell on three apparently excellent points, the two end colours and the colour of the spectral centre, but we could just as well take colours such as yellow, blue-green and purple as fundamental colours

COLOUR THEORY OF HERING

According to Hering, the nerves of vision undergo a chemical change when excited by impressions of light waves, such action being called dissimilation. In a state of rest opposite chemical reactions, called assimilation, restore the substance of our visual organs to their original state. Such chemical changes are conveyed to our brains as sensations of light and colour According to Hering there are four colour sensations—red, green, yellow and blue

Red and green, or blue and yellow, can never be found in a colour simultaneously, because they exclude each other These four colours, which have nothing in common with the physiological fundamental colours of Young-Helmholtz,

can easily be determined by means of coloured paper or transparent stained films

Hering further considers black and white as primary sensations and classifies the latter in the following pairs Red and green, blue and yellow, black and white

The three sensations are considered to be the result of the dissimilation and assimilation of three different substances contained in our organs of vision Dissimilation of the black and white sensitive substance causes the sensation of white, and assimilation of this substance causes the sensation of black The second substance is called red-green sensitive, the third yellow-blue sensitive Dissimilation of these two last-named substances corresponds to red and yellow sensations respectively, whereas their assimilation corresponds to green and blue sensations

All colours of the spectrum act in a dissimilating way upon the black and white substance, and mixed light appears colourless if it has equal assimilating and dissimilating power on the red-green and blue-yellow substance of our vision No chemical action takes place in this case, therefore the sensation of white is the result

The above theory enables us to explain better certain "subjective" light and colour sensations than is possible by the Young-Helmholtz theory, and it has found, therefore, the warmest support among physiologists.

B BODY COLOURS.

Light, when striking a body, may be absorbed, reflected or transmitted It may occur that only a part of the spectral rays composing white light is absorbed—*i e*, light of a definite wave length—and that the remaining rays are transmitted or reflected In this case the body appears coloured. If a glass plate absorbs the green rays of white light the glass will appear red, and we receive the impression of white light which has been coloured by the glass in process of transmission The light, however, in passing through the glass, has lost the green rays of white light by absorption,

red rays only remain unabsorbed and therefore reach our retina

In a similar way paper coated with Eosine appears red, because the rays reflected from its surface are devoid of the green rays of white light

If a body absorbs all white light it will appear black, if it reflects all rays, white, if it only absorbs a part, it may appear grey, and, finally, if the body reflects rays combining with each other as a coloured mixture, we receive the sensation of colour

Bodies exhibiting in powder form or in solution high absorptive powers for rays of certain wave lengths, and retaining their characteristic coloration after considerable dilution, are known as dyes and pigments In everyday life they are called "colours," a term which is to be avoided as it signifies a property of a body Under the name of dye we understand, however, a coloured substance used for colouring other bodies

As with coloured lights, we distinguish also in body colours "hue" and "tint" Moreover, the terms "purity" and "saturation" have a slightly different meaning when applied to pigment colours Purity signifies the absence of "black"; "saturation" depends upon admixture with white The term "intensity" is often used in preference to that of "saturation"

The brightness or "luminosity" of a coloured body depends upon its "specific" luminosity (see page 27)

Every colour may be considered as a mixture of a spectral colour with white, grey, or black, and the colour of any body may be defined by referring to a spectral colour of definite wave length (purple being excluded).

The colour of vermilion may be defined, for instance, by wave length $\lambda = 610\ \mu\ \mu$, which, of course, indicates the hue only

For the purpose of characterization of body colours comparison with colours of the spectrum is advisable.

In such cases it is necessary to isolate the spectral colours by means of the Helmholtz apparatus, illustrated in Fig 4

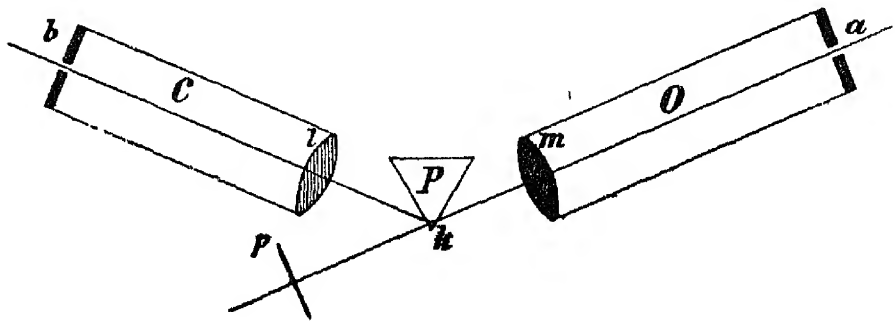

Fig 4

Remove the eyepiece of a spectroscope and replace with a tube having a narrow slit *a* through which we look towards the prism *P*, placed in such a way that *k* lies in the axis of the tube *m* This tube carries an objective lens *m*, *C* is a collimator tube with lens *l* and the slit *b* is directed towards the source of light

Looking through slit *a* we observe the surface of the prism illuminated with one colour only, which can be changed by shifting the tube *O*

As the prism only covers one-half of the field of view, we can place in the other a coloured glass plate *p*, which is suitably illuminated

By accurate adjustment of tube *O* we obtain even illumination of the field and are enabled to match the colour with a spectrum colour The adjustment of tube *O* will indicate the wave length of the colour

1. The Colour Circle and the Spectrum of Body Colours

If we imagine all pure colours to be placed within the periphery of a circle, in the order of the spectrum, we find complementary colours to be diametrically opposite and Hering's colours distanced from each other 90°

The colours ultramarine, chrome yellow, Eosine red and Acid Green may be taken as representing Hering's primaries Between two primary colours, we find the space filled

with their mixtures, resulting in a harmonious gradation from one into the other Hering's four primaries excite colour sensations altogether different from those which are excited by the triads derived from the spectrum, the former are, therefore, 90°, and the latter 120°

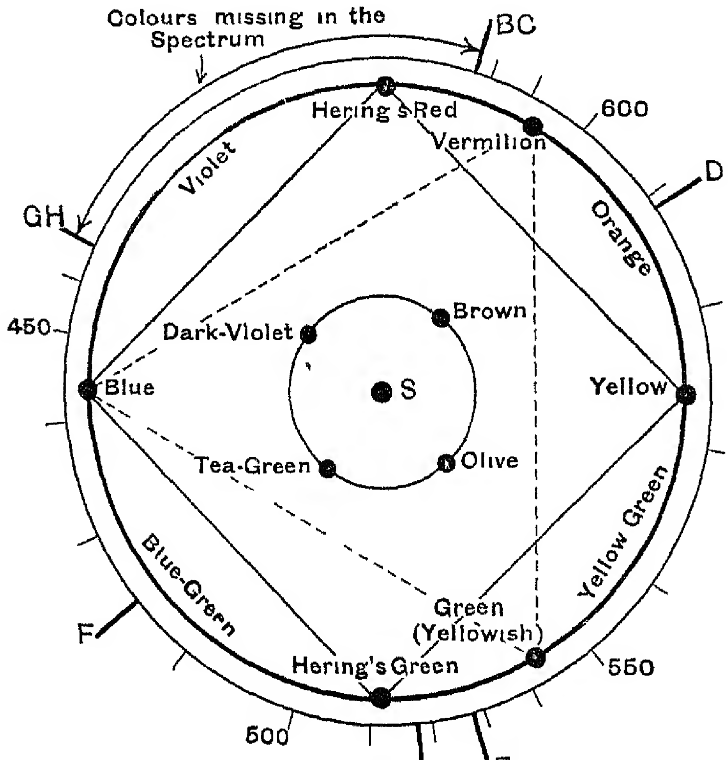

Fig. 5

distant from each other The blue of both is exactly the same By comparison with spectral colours, as described on page 33, we are in a position to ascertain the wave lengths, which are given in Fig 5

Such a wave-length scale extends from 640-440 $\mu\mu$ and is a very convenient means of determining the character of the colour of a pigment

Similar to the colour distribution in the spectrum we also find here the wave lengths of red, green and blue within narrower limits than those of blue, green and yellow

If we assume the centre of this circle to be represented by black, and every radius to be filled with gradations of colour between black and the pure spectral colour of the

periphery, we have a circle which contains colour shades, but if we assume the centre of the circle to be white, the circle will be filled with colour tints, which are colour mixtures of pure colours, primaries and secondaries, with white

Moreover, within this circle the wealth of colour is not exhausted, because there exist colour circles with different greys in the centre, still adding to the enormous number of possible colour shades

The following table gives a few of such mixtures and indicates their common names

	MIXTURES WITH		
Colour	White	Grey	Black
Purple	Pink	Wine Red	
Red	Pale Red	Copper Red	Brown
Orange	Flesh Colour	Chamois	YellowishBrown
Yellow	Straw Yellow	Greyish Yellow	Yellowish Grey
Yellow-Green, Green	Pale Green	Greyish Green	Olive
Blue-Green	Water Blue	Sage Green	Sea Green
Blue	Sky Blue	Blue Grey	Steel Blue
Violet	Lilac	Violet Grey.	Dark Violet

THE SPECTRUM OF BODY COLOURS

A coloured body absorbs one part of white light and reflects another, and the colour of the body is always complementary to that of the absorbed rays Our eye is not capable of determining the composition of the absorbed or reflected rays, and a spectroscope is, therefore, required Viewing the colour through the spectroscope we only perceive those colours which are reflected, whilst those which are absorbed form a shadow band, called the absorption band

It is, however, considerably easier to ascertain absorptions if we compare the partial spectrum with the complete one, for which purpose special comparison spectroscopes

are made In these instruments there are visible two spectral bands close to each other, enabling us to ascertain the weakest absorptions Coloured papers are always examined by reflected light For all examination of coloured liquids we use special glass tanks of wedge shape, enabling us to view different densities of the liquid The comparison spectroscopes of Zeiss, of Jena, have a wave-length scale, by which we can accurately measure the position and the width of the absorption band. A very convenient way of defining an absorption band is graphically, by means of curves, constructing upon a straight line, the wave length scale as abscissæ, and the intensity of the absorption band as ordinates For general use the ordinates are somewhat arbitrary, because they are not accurately measured, being obtained by purely ocular estimation If required, however, for mathematical calculation it is necessary to insert the ordinates according to careful measurement, for which purpose special instruments, called spectro-photometers, are made

Data obtained by such measurements give us the thickness of the absorption relief for different wave lengths, and such magnitudes are used as ordinates at corresponding points of the wave length scale, the result being a mathematically correct absorption curve

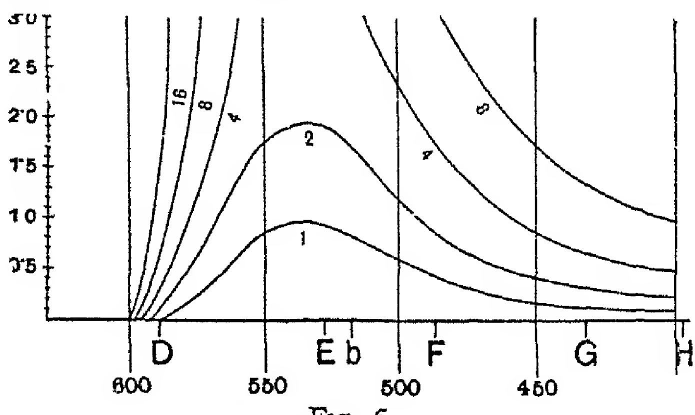

Fig 6

The unit for measuring the ordinates is the thickness of a film which transmits one tenth of the light striking it

Fig 6 shows a few curves, obtained by measurements

of gelatine films stained with Erythrosine in different degrees of intensity

Curve 1 indicates reflection and absorption respectively of all red and blue rays by a body of purple red colour, and an absorption maximum in the spectral green of wave length $\lambda = 530$ The ordinate scale records the density of the absorption relief in a film thickness of transparency of 0 1 The crest of the relief is about of thickness 1 It follows that our red coloured film transmits only one-tenth of the green rays of wave length $\lambda = 530$

The thickness of the relief diminishes rapidly towards blue, and near $\lambda = 500$ amounts to only 0 5

SPECTRAL PECULIARITIES OF BODY COLOURS

Absorption curve 2 represents the absorption of two films which are stained exactly alike and are superimposed Such absorption is defined by doubling the height of the ordinate curve By adding such films 2, 4, or *n* times, the height of the ordinate will increase 2, 4 . . *n* times. The absorption band, however, also widens sideways, which is distinctly noticeable in Fig 6, in particular towards the blue end of the spectrum

This peculiarity is common to all other body colours.

With increasing intensity of colour, absorption of the blue rays takes place, without, in some cases, stopping red rays

This fact explains the phenomenon of purple-red colours of the Erythrosine order losing completely, when in great concentration, the bluish shade, which is a characteristic of the very diluted colour Certain printing colours have a decided bluish hue when spread in thin layers, but are vermilion in dense layers

Blue-green, for instance, becomes blue in concentrated solutions, and certain blue and green dyes appear red in transmitted light

This peculiarity of body colours revealed by absorption spectra explains the fact, that although we know of bodies

completely reflecting red or green spectral rays, no body is in existence which, whilst intensely coloured, completely absorbs or reflects blue or green spectral rays This also explains why blue or blue-green bodies lack the brilliancy of colour which red or yellow objects exhibit

Fig 6 also shows an increasingly abrupt termination of the curve towards the red end of the spectrum with increasing concentration of colour By doubling the concentration we obtain considerable differences in the hue of the colour, but further increase diminishes such differences until a superposition of 16 stained films records an almost perpendicular termination of the curve

It is a well-known fact that the superimposing of a print in the same printing ink eventually results in a "limit colour" which no additional impression will alter in hue

2. The Components of Body Colours.

With very few exceptions, body colours always show gradually terminating absorption bands, and the colour of a body is never formed by a narrow well-defined spectral transmission There are, however, bodies, chiefly belonging to the order of dyes of the coal-tar group, which appear to show a very narrow absorption band On closer examination we find, however, that this band is by no means a narrow one, because it is surrounded by less visible absorption bands, these cannot escape quantitative examination, which proves them to be spread over one-third of the spectrum.

Absorption Band I in Fig. 6, for instance, corresponds to a very lightly stained Erythrosine film, yet we notice the absorption to extend over more than one-third of the spectrum The spectral composition of body colours is always due to rays of broad spectral zones which never show abrupt termination

As mentioned on page 24, the three spectral bands, red, green and violet, are fairly uniform in colour, and they

may be taken as representing the components which form the hues of all body colours

These elements can always be reproduced with great facility For this purpose the spectrum is split into three parts at wave length $\lambda=580$ and $\lambda=495$, and we obtain colours, the hues of which may be defined by the names of vermilion, yellow-green and ultramarine, and approximated by rays of wave length 610, 540 and 465

The luminosity of these three colours is equal to the sum of the luminosities of all rays composing this particular section of the spectrum, and we obtain by superposition of the three coloured lights a " white " equal to the " white" obtained by synthesis of all rays of the spectrum

Moreover, it is not absolutely necessary that these three colours, which are to form a system of fundamental colours, are composed of rays of these three spectral sections, they may be monochromatic or composed of different rays, because the resulting colour mixture depends entirely upon the hue and luminosity of the colours and not upon their spectral composition

To assume that the three spectral sections form unchangeable quantitative units is, of course, not quite correct, because body colours are more or less inclined to absorb the spectral yellow or yellow-green more than the blue-green, or the reverse may be the case

Each of the three spectral sections shows two differently coloured halves The green section, for instance, shows from 580 to 540 a yellow, from 540 to 495 a bluish hue, and by mixing the rays of either we obtain a yellow-green and a blue-green, which colours may be matched by mixing the fundamental green with a little red or blue respectively Such additions may amount to about 20 per cent, and we may assume the composition of the yellow-green section to be $\frac{4}{5}$ of fundamental green + $\frac{1}{5}$ of red, and that of the blue-green to be $\frac{4}{5}$ of fundamental green and $\frac{1}{5}$ of blue.

We may assume the yellowish red between 610 and

580 of the red section, and the greenish blue of the blue section to each contain 20 per cent of green

Although such numbers can only approximately serve to characterize the composition of spectral colours, they enable us to demonstrate the facts in the following examples

Fig 7 represents the transparency curve* K K of a gelatine film stained with Prussian blue, and shows almost total absence of red transmission, but medium and total transmission of green and blue rays respectively

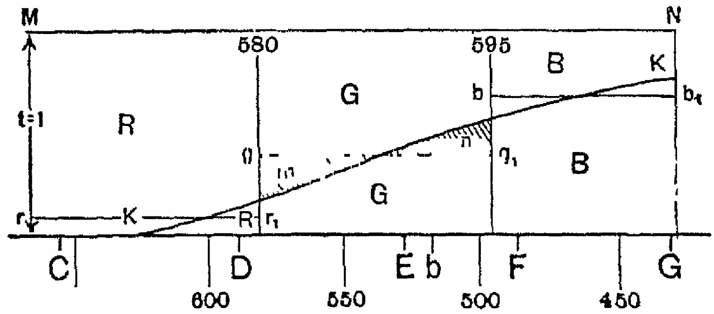

Fig 7

This diagram shows in a graphic form the three spectral sections R, G, B, which form the colour of Prussian blue, and the amount of each necessary for its composition

They are by no means identical with the three fundamental colours, which may be represented by *rr*, *gg*, and *bb*

The curve represents the actual colour and the steps *r*, *g*, *b* the colour derived from a mixture of three unchangable fundamental spectrum sections

We note considerable difference in the colour composition, which shows the error in the assumption that the red, green and blue rays transmitted by Prussian blue are identical to those of the fundamental colours

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*We understand by transparency the light intensity i transmitted by a coloured film, in proportion to the light intensity I of the light striking the film

$$t = \frac{i}{I}$$

The transparency of a perfectly transparent body is $t = 1$, but for less transparent bodies will, of course be a fraction

The relation between the thicknesses of the absorption reliefs, *e g*, of the ordinates z of the absorption curve to the transparency t is given by the equation

$$z = -\log t$$

The quantities of the three components are proportional to the area of the three surfaces R, G and B

1 Red + 7 Green + 10 Blue (I.)

The red and blue differ very little from the fundamental colours, but the green is considerably bluer

The green component of the stained film is —

7 Green — 0 2 red + 0 2 blue,

and to reproduce the original colour, by means of the fundamentals, the following is required ·—

0 8 Red + 7 Green + 10 2 blue (II)

If, however, we build up by means of a rotating colour disc, we require for

I	20° Red +	140° Green +	200° Blue
II	16° ,, +	140° ,, +	204° ,,

Yet we notice no difference in both colour mixtures

It follows from the above that it is permissible to consider the three spectral sections, *viz*, page 24, as the components of all body colours.

GRAPHICAL REPRESENTATION OF BODY COLOURS

On the basis of the above assumption we represent in Fig 8 the composition of body colours and the peculiarities of their mixtures *r*, *g* and *b* represent the quantitative unchangeable red, green and blue spectral sections and the black indicates the quantity of absorbed rays

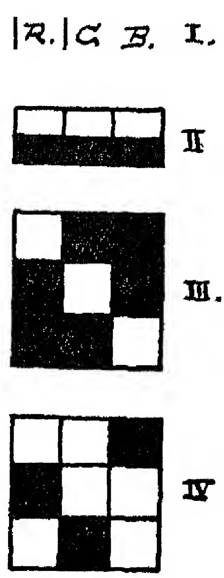


Fig 8.

1, is a body reflecting the rays of all three sections and absorbing none—*i e*, a white body

2, reflecting equal amounts in all three sections, but also absorbing equal amounts—*i e*, grey body

3 Reflecting the red or green or blue rays only—thus appearing red, green or blue respectively

4 Two sections reflected —
Red + Green = Yellow
Green + Blue = Blue-green
Blue + Red = Purple

The three fundamental colours, called primary colours, form a second well-defined colour system, that of secondary colours

If the rays of two spectral sections are not reflected in equal quantities, we obtain colour mixtures, as, for instance, the orange in 5 which is composed of 1 part of red and $\frac{1}{2}$ part of green

All colours dealt with so far show the highest purity and saturation that it is possible to find in body colours If a body, however, reflects less than the above-mentioned colour components, we have a colour which is of lesser luminosity, and which appears of a blackish hue.

We find a representation in 6, for instance, of a blackish orange—a colour known as " brown "

Whitish orange, however, composed of 1 part of Red + $\frac{2}{3}$ green + $\frac{1}{3}$ blue is represented in 7

To find the result of a colour mixture of two or more colours, or coloured lights, we simply add the three colour components For instance, yellow and blue-green = a whitish green, which is formed of a mixture of 1 part of red + 2 parts of green + 1 part of blue Knowing that equal parts of the three fundamental colours are equal to white, we expect to obtain a whitish green

In a similar way we arrive at the conclusion that the colours

Red + blue-green

Green + purple

Blue + yellow

combine to form white, and are, therefore, called complementary No difficulty presents itself in ascertaining the complementary to any other colour It becomes a matter of course that 5 (Fig. 8), representing orange, must be complementary to a blue-green of composition ; 1 part blue + $\frac{1}{2}$ part green.

ABSORPTION BAND AND BODY COLOUR

The absorption band determines the colour of a body, but the reverse is not true, because the same colour sensations may be produced by a variety of different colour mixtures, showing altogether dissimilar absorption bands.

This uncertainty as to the absorption spectra is ended if we assume that all body colours are built up by the fundamentals red, green and blue, and that the spectral transition colours, yellow, blue-green and violet, play no part in the formation of colour

All pure yellow bodies have to show, for instance, strong absorption of the blue section, and all pure blue bodies of full saturation record absorption of the red and green when spectroscopically examined

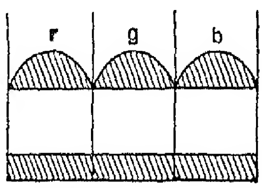


Fig 9.

The position and shape of the absorption band is, therefore, more or less conditioned by the colour of the body, although showing differences in minute details The weakening of a fundamental spectral section may be indicated by a general absorption, or a maxima in different places, but the result will be the same

A very characteristic example is furnished by a grey, obtained by superposition of blue-green, purple-red and yellow films The absorption spectrum of this grey body is given in I., Fig 9, but the grey obtainable by mixing carbon black with a white pigment shows the absorption ratio given in II , Fig 9

3 The Mixing of Body Colours

Whenever we speak of mixing colours we think of a mechanical union of pigments or dyes There is, however, another method of body-colour mixture to be considered,

namely, the union of rays of light reflected or transmitted by a body, and best demonstrated by superposition of such projected lights upon a white screen If we project the light transmitted by a red glass upon the light transmitted by a green glass, we obtain a mixture of red and green rays, or the colour sensation "yellow"

By decreasing the amount of projected rays of the one or the other by interposition of colourless plates, we get gradations of colour from red over yellow to green If we project blue light by means of a third lantern we can, by careful adjustment, recompose white light or get an endless variety of all possible transition colours The law of the mixture of spectral colours holds good in this case, because the resulting colour mixture depends entirely upon the hue of the projected lights, and not upon their spectral composition The above-mentioned method of combining body colours is called "additive," because the different colour sensations are added upon our retina

ADDITIVE COLOUR MIXTURE

A very convenient way of adding rays reflected from a surface is by means of the colour-top We put the different colours upon a cardboard circle of about 20 cm diameter in the form of segments, and on rotating it the colours will blend into one uniform colour The colour sectors can be measured, and they give the quantities required for the desired colour mixture

For rotating the disc a small electric motor, or a clockwork, or hand-turning apparatus can be employed. The speed of one revolution should be at least $\frac{1}{20}$ to $\frac{1}{50}$ of a second

To compare the colour mixture with a given colour, or with a colour produced by different components, it is usual to employ smaller discs of such colours, these smaller discs being rotated with the disc carrying the strips of paper which are under examination

Fig 10 shows such an arrangement *a* represents chrome yellow, *b* ultramarine, and to detect false calculations as to the resulting grey, two smaller segments *w* and *s*, made of black and white paper, are inserted The four

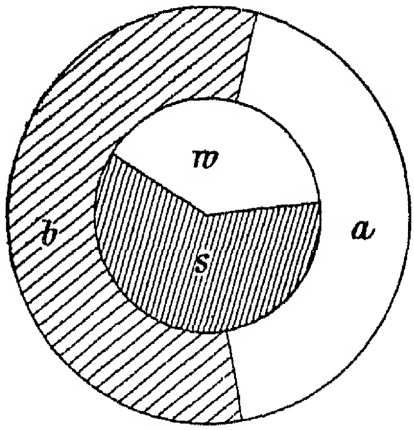


Fig 10

segments are, after rotation, shifted until an even grey tone is obtained Measurement of the periphery segments record 137° chrome yellow, 223° ultramarine, 147° white, and 213° black

A combination of rays of 0 38 parts chrome yellow and 0 62 parts of ultramarine, are equivalent to a mixture of 0 41 parts of white with 0 59 parts of black This may be expressed by the following equation

$$0\ 38 \text{ chrome yellow} + 0\ 62 \text{ ultramarine} = \begin{cases} 0\ 41 \text{ white} + \\ 0\ 59 \text{ black.} \end{cases}$$

That it is never possible to combine on a colour-top complementary pigments to white is, of course, explained by the fact that such pigments reflect only part of the spectral rays which are distributed over the whole circle area

The result will be a grey, which in the most favourable cases is composed of equal parts of white and black

In this respect colour-top mixtures differ considerably from superpositions of coloured lights by lantern projection, where pure white can be recomposed from the complementaries

Mixing of coloured light is also possible with the help of mirrors, as demonstrated in the Photochromoscope.

Fig 11 shows such an arrangement A closed wooden box has openings R, G and B, which are covered with red, green and blue glasses The interior shows three adjustable mirrors S_1, S_2, S_3, which reflect the light

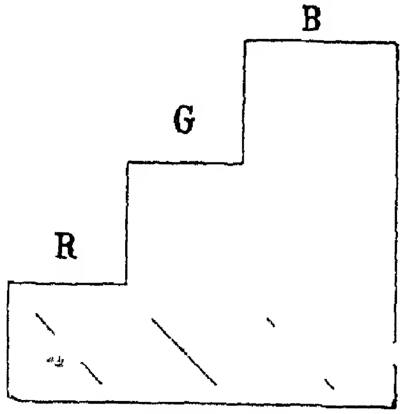


Fig 11

filtering through the coloured glasses towards opening O Mirrors S_1 and S_2 are uncoated thin glass plates, but S_3 has the usual silver deposit

The light which is transmitted through the red glass is reflected by mirror S_3, passes through the two transparent mirrors S_2 and S_1, and reaches the eye at O The light which passes through the green and blue glasses will be reflected by the surface of mirrors S_1 and S_2 towards O, and the observer will receive one impression of the resulting light mixture By careful adjustment of the coloured glasses, we obtain "white," and reducing the amount of light filtering through one or the other, all possible colour tints may be obtained

A method, involving the same principle of mixing reflected rays, is that of placing coloured lines or dots close to each other, the dots being so very minute that the eye cannot detect the components of the resulting colours. Such methods are greatly used in textile industries in the manufacture of tapestries, also in printing processes, and in oil or water-colour painting, where colours are placed side by side, reflecting rays which are united on the retina into a single colour impression Vermilion and ultramarine appear violet, red and green appear

yellow, etc Modern colour photography with colour screen plates is based upon this principle

Such plates are formed by microscopically small dots or lines of the three primary colours, red, green and blue, and appear by transmitted light of a delicate grey colour By obscuring one or the other of the primaries all possible colours are obtainable The principle of such processes is similar to that of colour projection, the colours are, however, not superimposed, but are placed side by side

MIXTURES OF PIGMENTS AND DYES.

Very different, however, are the results of light mixtures produced by mechanical union of coloured bodies If we coat a white surface with a dye or pigment we prevent this surface from reflecting a certain species of rays, and the white surface will, therefore, appear coloured If we coat the surface a second time with a different transparent dye, the latter will absorb some rays which the former reflected, and the colour sensation and luminosity will be altered

If we coat white paper with Eosine, which absorbs green rays, the paper will appear red, because

white — green = red.

If we again coat this paper with a yellow dye which absorbs blue rays, the paper will appear orange, because

white — green — blue = orange

Every subsequent addition of colour will absorb certain rays of light, and will alter the colour and its luminosity until no more light is reflected, when the surface will appear black If we mix pigments, they will act in an analogous manner, the different particles of the pigments absorbing certain rays of light, and only those rays which are not absorbed produce a colour sensation We notice the same phenomenon when coloured liquids are mixed or coloured glasses are superimposed

We find that in the case of pigmentary mixtures, the amount of colour forming light rays is reduced, a procedure

which is termed "subtractive" colour mixture The following law may be formulated The absorption spectrum characteristic of the colour hue and the colour shade of a pigment mixture may be obtained by adding the absorption bands of the pigments

The mixture of coloured lights, reflected or transmitted by a body, is equal to the sum of the light rays, but the result of pigmentary mixtures is determined by the sum of their absorption spectra Both mixing methods are subject to definite laws, and both may be termed "additive"

The usual belief that the result of pigmentary mixtures is not subject to the laws of colour mixtures is by no means correct. The colour mixture is entirely dependent upon the absorption ratio of the components, and as similar coloured bodies show almost similar absorption bands, the mixture of dyes or pigments is, generally speaking, subservient to the laws of coloured light mixture; but a mixture of coloured bodies always results in a widening of the absorption band, or in other words, in the production of black The narrower the absorption bands the purer will be the colour mixture in hue, the broader the absorptions the more will the actual colour mixture be degraded by black

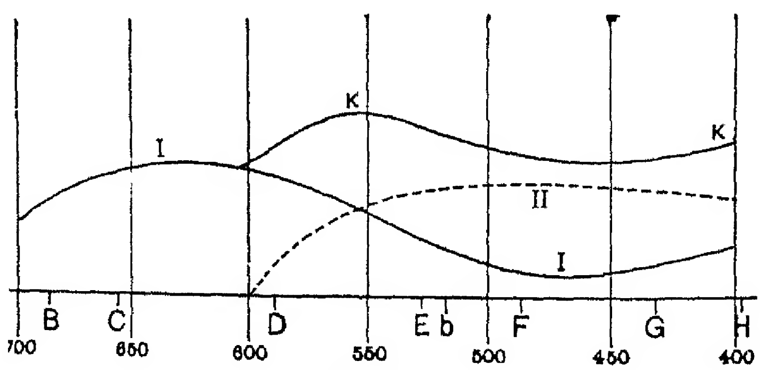
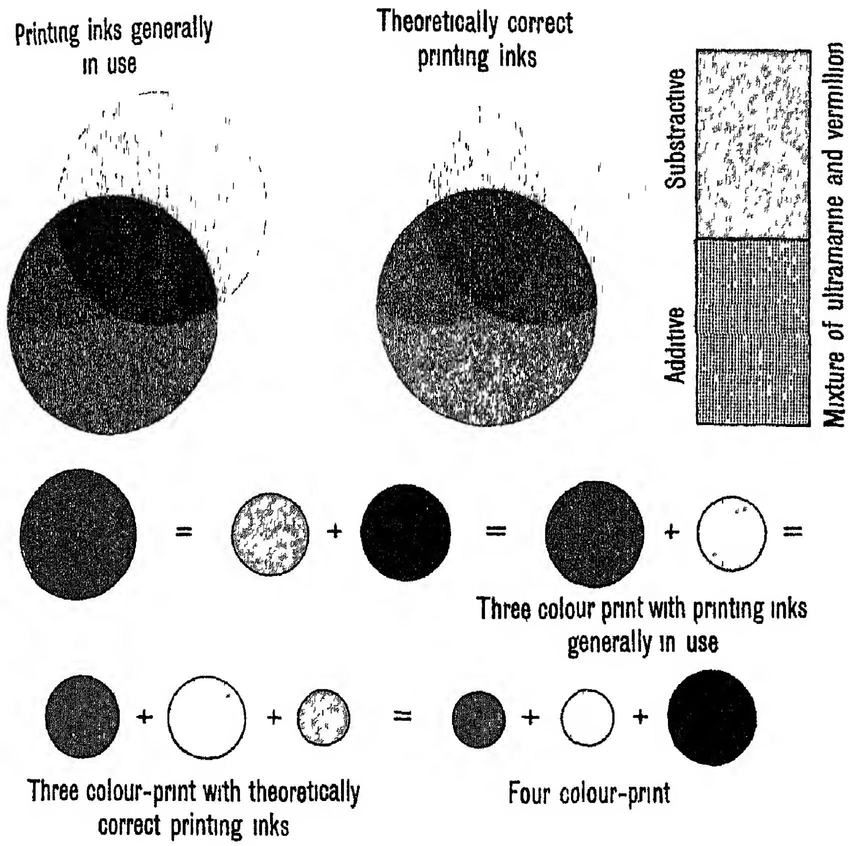


Fig 12

If we mix, for instance, a red and a blue pigment, we should expect to obtain a purple slightly degraded by black, yet if we mix vermilion with ultramarine we obtain a reddish-brown mixture.



three colour photography.

This irregularity is, however, explained by the absorption spectra of the two pigments (Fig. 12).

Ultramarine has, like all blue pigments, a very impure colour which, as absorption band I. shows, extends over the whole spectrum, but the vermilion represented by curve II. is a pure red. If we combine the two curves, we obtain curve K K, which is characteristic of the hue of the mixture.

This curve has a maximum in the green of the spectrum, and would represent a blackish purple, were it not for a considerable absorption in the blue, which permits of the passage of a small amount of red rays only, the resulting mixture being a dark brown. If, however, we mix vermilion and ultramarine on the colour-top we obtain a whitish purple, an altogether different colour from that obtained by mechanical mixture of the pigments.

This explains the difference in the behaviour of colours, when printed either as a screen tint or as a solid tint.

Colour supplement I. shows ultramarine and vermilion printed in dots, separated from each other, resulting in a purple colour tint, but when laid over each other giving a brown. If the lines, however, cross as in Fig. 13,

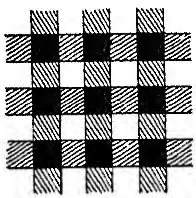


Fig. 13.

the luminosity of the colour will be decreased, and the colour tint will be the more degraded as the space is more covered by the overlapping of the coloured lines. If we superimpose half-tone gradation scales in two different colours we find that the colour tint of this scale

is by no means uniform, because the darkest end will correspond in tint to the mechanical pigment mixture, but in the light parts to the mixture of coloured rays.

SUPERPOSITION DEFECTS.

It has generally been regarded as immaterial whether two colours were mixed before printing, or whether they were superimposed on the paper. This view is only correct if we work with perfectly transparent pigments or dyes which are not too opaque. In practical work this condition cannot be observed, and the last printed colour always predominates.

White paper printed in yellow and then in red ink should appear yellow-orange, but we obtain a red-orange, because the yellow is partly absorbed by the red with which it is superimposed. We term this phenomenon the "superposition defect." As is well known, printers' inks and painters' colours vary greatly in this respect, but even the most transparent colours, if used in concentrated form, prevent the full effect of the underlying colour being obtained.

The following experiment will prove this statement. Coat one half of a piece of white paper with an even layer of chrome yellow, and the other half with Rose Bengal, overlapping both colours where they meet. Cut a large disc of the superimposed colour, and two smaller ones of single colours, for experiments with the colour-top

To match the colour of the large disc the yellow and red sectors must be equivalent. To obtain similar colours on the colour-top it will be necessary to form a combination of the large disc with white sectors.

The colour of the large disc equals a mixture of one part of chrome yellow and two parts of Rose Bengal, instead of equal proportions of both dyes, which would be in accordance with theory.

The transparency of a colour is, of course, dependent upon its concentration, which will govern the magnitude of the superposition errors.

A deep red will reflect the impinging rays before they can reach the yellow surface underneath, whereas a very transparent layer of red may permit a free passage to the yellow. This accounts for the irregularity in colour hue when we attempt to produce a colour scale. If we print a red scale over a yellow one we find the lighter tints to be yellow-orange and the deeper ones red-orange.

This superposition defect is extremely marked in the case of three printings, where the first print can hardly exert its influence if the other two are saturated colours.

COLOURED ILLUMINATION.

A similar alteration of colour takes place if we cover a coloured surface with a coloured glass, and it is immaterial whether the glass is in close contact or not. A blue dye viewed through a yellow glass appears green, precisely as does the mixture of blue with yellow.

Illumination with coloured lights gives analogous effects. Artificial illuminants, especially candle, gas and electric incandescent light, are yellow, if we take daylight as white, and their spectra are not as rich in green, blue, and particularly blue-violet light, as is that of daylight. In such light, coloured bodies appear as if coated with a yellow film, and we cannot distinguish between light yellow and white, or blue and blue-green, or purple and red. Impure greys, if viewed by artificial light, appear of a yellow-brown colour, but pure grey remains a neutral tint. This explains why three-colour transparencies containing impure greys greatly change their character when viewed in artificial light. Even electric light must, if compared with daylight, be considered as a yellowish illuminant. The light of an artificial source can be made white by reducing the red and green rays in comparison with the blue, which can be done by passing the light through a filter composed of Patent Blue and Rose Bengal.

4. Geometrical Representation of Colour Mixtures.

If we imagine at the points A and B, Fig. 14, two colours and between the two points a harmonious scale of a mixture of the two colours, we may term the line A B the mixing line of the colours A and B. If we take A to

Fig. 14.

represent yellow and B red, we can place in line A B all possible gradations of yellow-red colour mixtures, and we find in point b a mixture of one part of yellow and two parts of red because A b=2B b. If we imagine A B to represent weights of the quantities of the mixing colours, we find the quantity of mixed colour within the line by adding the assumed quantities A B.

This geometrical representation of colour mixtures is equally applicable to coloured light mixtures, but, of course, the standard by which to measure the quantities of the composing colours will be a different one. When actually mixing the pigment substances we can insert the weights, but in the case of colour-top measurements, the area of the sectors, and, in the case of spectral light mixtures, the luminosities are used as factors.

In the case of light mixtures by means of mirrors, as, for instance, in the Photochromoscope, luminosities are used as the factors. If we diminish the luminosity by the interposition of diapositives, we find their transparency to correspond to the quantity of the lights to be mixed.

The mixing line of pigments will contain colour shades, that of coloured lights contains colour tints. A point in the mixing line of two complementary colours will, therefore, record pure black or grey in the first, and pure white in the second case. If we wish to combine the colours A and B with a third C, we can take any point outside the

mixing line for the third colour, Fig. 15, and consider every line drawn from C to any point on line A B the mixing line of the respective colours. According to this assumption all colours obtainable by mixing A, B and C are to be

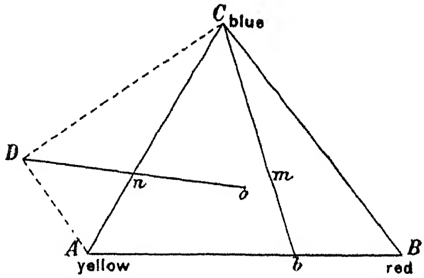


Fig. 15.

found within the triangle A B C. If we take C to represent blue, we find within A B all orange, within A C all green, and within C B all violet colour mixtures and the triangle filled with continuous colour shades. Such a surface will be called a "mixing triangle."

Corresponding to the origin of this mixing triangle we are enabled to find the point characterizing a certain colour in the following way :—

Imagine at the points representing the colours to be mixed, weights equivalent to their quantity, and let us ascertain the centre of gravity of such a system, which will give us the geometrical position of the mixed colour. If, for instance, one part of yellow is to be mixed with two parts of red and 1·5 parts of blue, we imagine A, B and C, corresponding weights. Considering A and B first, the centre of gravity will be at b, and we have to imagine at this point a colour corresponding to a mixture of one yellow and two red = a weight of 3 units, *viz.*, three parts of orange. Line b, C has now 3 units in b and 1·5 units in C and the centre of gravity of the line is in m, because $Cm = 2\ bm$.

The point m is therefore the centre of gravity of the

whole system, and its position corresponds to a colour derived by mixing 3 parts of orange + 1·5 part blue, and also to that of a mixture of 1 part of yellow + 2 parts of red + 1·5 part of blue.

Because the colours on the lines are assumed to be less pure than the colours in the corners of the triangle, the colours within the triangle will be considerably reduced in purity, because they are mixed with various proportions of black or white respectively. If one of the corner colours is complementary to a mixed colour on a mixing line we obtain, in the case of coloured lights, a point of pure white within the mixing surface, which neutral point will in the case of pigments be represented by grey or black.

THE COLOUR TRIANGLE FOR ADDITIVE COLOUR MIXTURES.

If we imagine in the corners of the triangle the pure fundamental colours (page 39) we assume the triangle to enclose all possible body colours. The fundamental colours are formed by the addition of all rays of one particular spectral section and they will naturally serve as units. We must also assume equal saturation for the three fundamental colours, because purer red, green or blue body colours do not exist. This assumption is illustrated by an equilateral triangle, with white as the centre. Supplement II. shows such a colour triangle. The centre is white, the corners represent fundamental colours, and the sides of the triangle are mixing lines of two fundamental colours. In the middle of the line red-green, we find, for instance, pure yellow, towards the red all orange colours, towards green all yellow-greens.

In the middle of the other two sides of the triangle we find blue-green and purple, both nearer to the white than the fundamental colours, and therefore less saturated. Pure yellow, except golden yellow, always appears whitish if compared with pure red, green or blue. The same holds good with blue-green and purple. Their position, being

nearer to the white than the fundamentals, is therefore justified.

The three sides contain all pure colours, and the interior of the triangle all whitish colour mixtures. The above-mentioned method also serves for a graphical representation of colour mixtures. If we mix, for instance, equal parts of yellow and blue-green we obtain a whitish green *g* (page 42), which may be composed by mixing one part of green and three parts of white. Blue-green+purple and purple+yellow give a whitish blue and vermilion.

Totally different results are obtained by using a colour circle (page 34) which assumes equal saturation for various body colours. The centre of such a system—white—would naturally be equidistant to every part of the periphery, which includes a great number of pure colours, and not the three fundamentals only. But we find in this case that the yellow formed by mixing red and green is more whitish than that which deeply yellow coloured bodies show.

This, however, does not correspond with practical experience because red + green will give us a yellow equal to a chrome yellow of full saturation, although there are green bodies which appear more saturated in colour than a mixture of yellow + blue-green.

It follows that the three fundamentals are quite sufficient for the reproduction of all body colours. The colours are isolated by means of light filters, which consist of gelatine films stained with coal-tar dyes of relatively abrupt absorptions. Absolutely abrupt dissection of the spectrum into three sharply defined bands is not possible, because all dyes show a more or less gradual absorption band. The nearest approach to an ideal division is illustrated in Fig. 16. The shaded parts correspond to the absorption bands of the filters and we see that, although it is possible to limit the rays of the red section, the green and blue filters show general absorption. Towards the blue

end of the spectrum all absorption curves (*vide* page 37) show gradual termination. If we superimpose the three

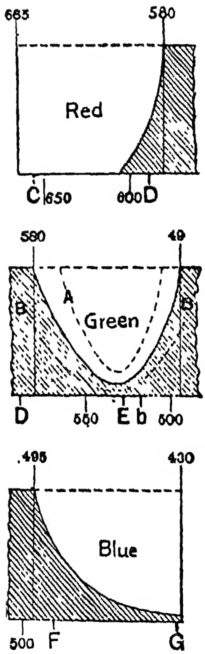


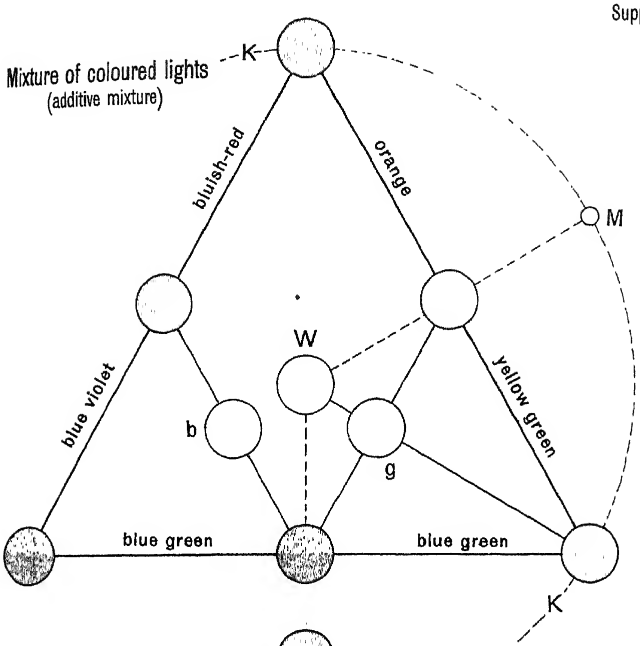
Fig. 16.

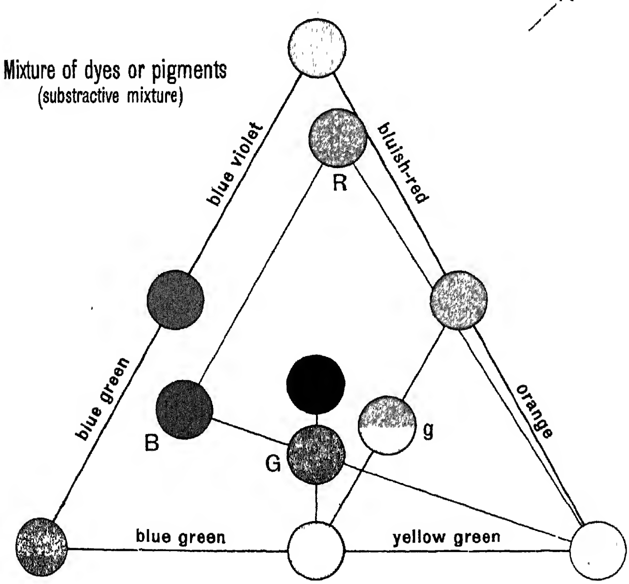
coloured lights of the filters, we do not obtain a pure white but a white of a pinkish hue. If pure white is required the intensity of light passing the red filter has to be considerably diminished, or the density of the blue and green components has to be diminished by addition of white. To neutralize a pure vermilion, for instance, we have to use green and blue containing 1/3 and 1/5 of white respectively. Such filters are used in three-colour projection and the conditions of a re-composition of pure white have to be fulfilled.

Strictly speaking, we do not possess three fundamental colours capable of exactly reproducing all colours of nature, but the resulting errors in practical work are very minute.

THE COLOUR TRIANGLE FOR SUBTRACTIVE COLOUR MIXTURES.

If we are to select three pigments which are to reproduce all colours, we have to select pigments with very narrow absorption bands, because by mixing pigments the absorption bands are made broader still. Experience teaches us that pigmentary mixtures of red and green do not give yellow and that it is necessary to use the secondary colour system of yellow, blue-green and purple. If we mix two of these colours we obtain, due to the addition of their absorption spectra, red, green and blue; purple and yellow gives, for instance, red, and if the purple





three colour photography.

is added gradually to the yellow pigment we obtain a complete range of all the orange hues.

The result is similar to that of mixing red light with varying quantities of green light. In both cases a continuous order of transition colours is obtained. We are, therefore, enabled to represent pigmentary mixtures by means of geometrical constructions.

In order to construct such a colour scheme, we insert the three pigments, yellow, magenta-red and blue-green in the corners of an equilateral triangle (Supplement II.). These three colours have to be as pure and saturated as it is possible to obtain in pigments, and the quantities required in each corner are to be so adjusted as to ensure a neutral grey in the centre. Such quantities are to serve as units. The centre of gravity of this system, being equidistant from these three points, represents, therefore, black. Every side of the triangle contains all colour mixtures which may be composed of two fundamental colours, and on every line drawn through the centre we find all possible colour shades. They are mixtures of black and of a pure colour which is represented by a point of intersection on the side of the triangle.

Equidistant from the corners on each side of the triangle are found the mixed colours red, green and blue, the primary fundamental colours. They are nearer to the centre black and are, therefore, less pure if compared with the colours in the corners of the triangle.

This triangle encloses all conceivable colour shades, and proves that the reproduction of all colours is possible by means of the above-mentioned three fundamental colours. If we mix in equal proportions the colours which bisect the sides of the triangle, for instance, red and green, we get the colour *g*, and as this point is three times as far removed from the yellow as it is from the black, it corres-

ponds to a mixture of 1 part of yellow + 3 parts of black. Experiment also proves that red and green give a very impure blackish yellow.

The colour triangle shows also, that the mixture of a green and a blue dye is a very impure blue-green, which is as different from the blue-green of certain aniline dyes as the yellow of a red-green mixture is to that of pure yellow. We observe the same in the case of blue and red mixtures giving a very impure violet.

As mentioned above, the interior of the triangle is filled with blackish colour shades, and we may assume in B, for instance, the impure greenish blue, known as Prussian blue. If we mix this blue with yellow we get in G a blackish green, known as silk green, and composed of 2 parts of pure green and 3 parts of black. The colour triangle explains many phenomena of pigmentary mixtures, which the colour circle does not explain. In the colour circle we find all pure colours equidistant from the centre, and accordingly vermilion and green should give a yellow, which is as pure as the vermilion formed from purple, red and yellow. This, of course, is not the case and a circular colour scheme is therefore useless if applied to problems of pigmentary mixtures.

Dr. L. Pfaundler has shown in one of his recent articles* that the colour circle is useless for answering physiological questions or those of colour photography. The circular colour chart has to be replaced by a triangle with a flattened apex, and such a colour construction will prove the assumption of a trichromatic reproduction of all colours, whether coloured lights or carefully selected pigments are employed. Experience, however, shows that pigmentary mixtures do not obey fixed laws like light mixtures do. The reason for this is found in the imperfections of the pigments selected to form fundamental colours, because each one should

*"Year Book of Photography," 1910.

completely reflect two spectral sections, absorbing one, a condition which the present aniline dyes cannot fulfil.

The colour chart only holds good in the case of pigments with well-defined absorption and with the characteristic intensification of its colour by superposition of various

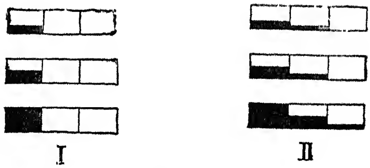


Fig. 17.

layers according to Fig. 17, I. All blue-green pigments, however, show absorptions, represented in Fig. 17, II. Even by slightly increasing the thickness of the pigmentary layers the absorption extends into the green spectral section, reaching finally impure blue-green. Magenta-red shows similar absorption characteristics, looking very like vermilion when applied in very thick layers.

The accuracy of the colour chart depends upon the spectral peculiarities of the selected fundamentals, and only shows obedience to the laws of pigmentary mixtures when coal-tar dyes are selected as primaries.

Mixtures of Coal-tar Dyes. The dyes Erythrosine, Patent Blue and Filter Yellow answer more or less to the above requirements. In proportion 0·5 : 0·2 : 1·0 they give a neutral grey or black.

We insert the above in our colour triangle and consider same as units of the fundamental colour system, Fig. 18. We can use, for mixing experiments in place of dyes, dyed gelatine films which are superimposed. The units are represented by numbers, indicating the numbers of films, not weights.

The films: Erythrosine 0·5+Patent Blue 0·2+Filter Yellow 1·0 gives a dark grey when superimposed, the absorp-

tion spectrum of which is shown in Fig. 19. The transparency of such a combination is approximately 0·07, which

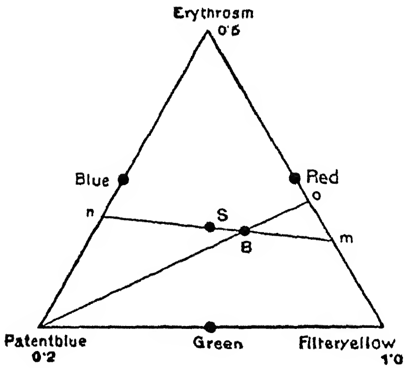


Fig. 18.

is too great for diapositives, but which gives a deep black when applied to paper prints, the transparency of the grey being reduced to $0{\cdot}07 \times 0{\cdot}07 = 0{\cdot}0049$.

Such considerations are very important, because they show that the layer of pigment is very thin in the case of paper prints, and that the above-mentioned differ-

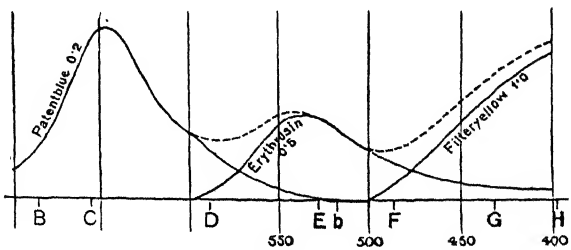


Fig 19.

ences in the hue of a pigment due to increased concentration are not so very noticeable.

The densities of the three fundamental colours which are required to obtain a given colour compound may be easily obtained by means of the colour triangle, Fig. 18. To get a vermilion for instance we have to mix one unit of Erythrosine

with one unit of Filter-Yellow or superimpose an Erythrosine film of density 0·6 with a Filter-Yellow film of density 1·0. This experiment shows that we obtain a brilliant fiery red. Patent Blue 0·2+Erythrosine 0·5 gives ultramarine and Patent Blue 0·2+Filter-Yellow 1·0 furnishes a green of high purity. To ascertain the densities of the three fundamentals for a colour mixture of yellow-brown hue indicated by B, we have to bear in mind that the side of the triangle [illegible] yellow is divided in 0 in proportion 1 : 1·4, 0 B being about $\frac{1}{4}$ of the line connecting Patent Blue with 0.

We have to take, therefore, one unit of Erythrosine+ 1·4 Filter yellow + 7·2 Patent Blue. To obtain the same results with coloured films, Erythrosine 0·5+Filter yellow 1·4 + Patent Blue 1·5 are required.

The colour triangle also teaches us that this brown may be compounded by addition of 2·5 parts of black to a colour represented by *m*, and that *m* is an orange, equivalent to a combination of 0·5 Erythrosine + 2·5 Filter yellow. Complementary to this colour is a greenish blue *n*, formed by superposition of films Erythrosine 0·5+Patent Blue 0·4.

MIXTURES OF ARTISTS' COLOURS AND PRINTING INKS.

To attempt to reproduce all body colours with the help of three artists' or printers' colours is a much more difficult problem. Such colours have to be permanent and are very impure in hue if compared with coal-tar dyes. This is particularly noticeable in the case of blue-green and magenta. For technical reasons it is generally necessary to take a very impure blue which contains a great deal of black, and a red which is not blue enough.

The colours referred to are inserted in the triangle in Supplement II., and are indicated with letters B and R.

Using a pure yellow we construct a triangle B R G, which contains a limited number of colour shades only. We are able to reproduce pure orange or red, but it is impossible to mix pure greens, blues or violets. It is easily understood that impure components cannot give a pure

mixed colour, and the difference between a pure green pigment and a green derived from mixtures of blue and yellow is well marked.

On the other hand, it seems peculiar that green G, formed by mixing blue B and yellow, should contain three parts of black and only two parts of pure green, which is a high percentage of black.

INFLUENCE OF BLACK UPON THE PURITY OF PIGMENTS.

We generally underestimate the amount of black in a colour mixture and Prussian blue, which appears fairly pure, contains 50 per cent. of black. The addition of 10 to 20 per cent. of black to a white pigment produces no marked change except in comparison with pure white.

A colour top mixture of equal parts of black and white appears light grey and by no means midway between black and white. Only if 20 parts of white are mixed with 80 parts of black, we obtain a grey, which we, however, expected to get by using equal quantities of black and white.

A white surface, however, ruled with fine black lines shows very different results, and we have to face a difference between objective luminosity and subjective sensation, defined by "Fechner's law." This law can be verified by colour top experiments. For this purpose white paper is ruled with black lines of different thicknesses representing five different luminosities. The width between the lines varies between 0·05 and 0·40 mm., and the luminosity of such a screen can easily be ascertained by measurement of width of lines and spaces, and imitated by black and white sectors on the colour top. The screen is to be viewed at a distance at which the lines are still visible. Although the colour of surface does not appear homogeneous, with a little practice and repetition of the experiment, a comparison between the two tones is possible.

The objective luminosity of the grey on the colour top is known to us by its composition and permits a comparison with the subjective luminosity of the screen. The result

is graphically illustrated in Fig. 20. The objective luminosities form the abscissæ, and the subjective sensations form the ordinates. If subjective and objective luminosity are equal the straight line *o a* would be the result, because a screen luminosity of equal parts of black and white would correspond to a colour top luminosity of 0·5.

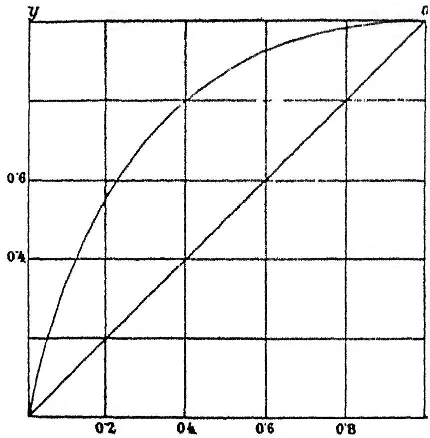
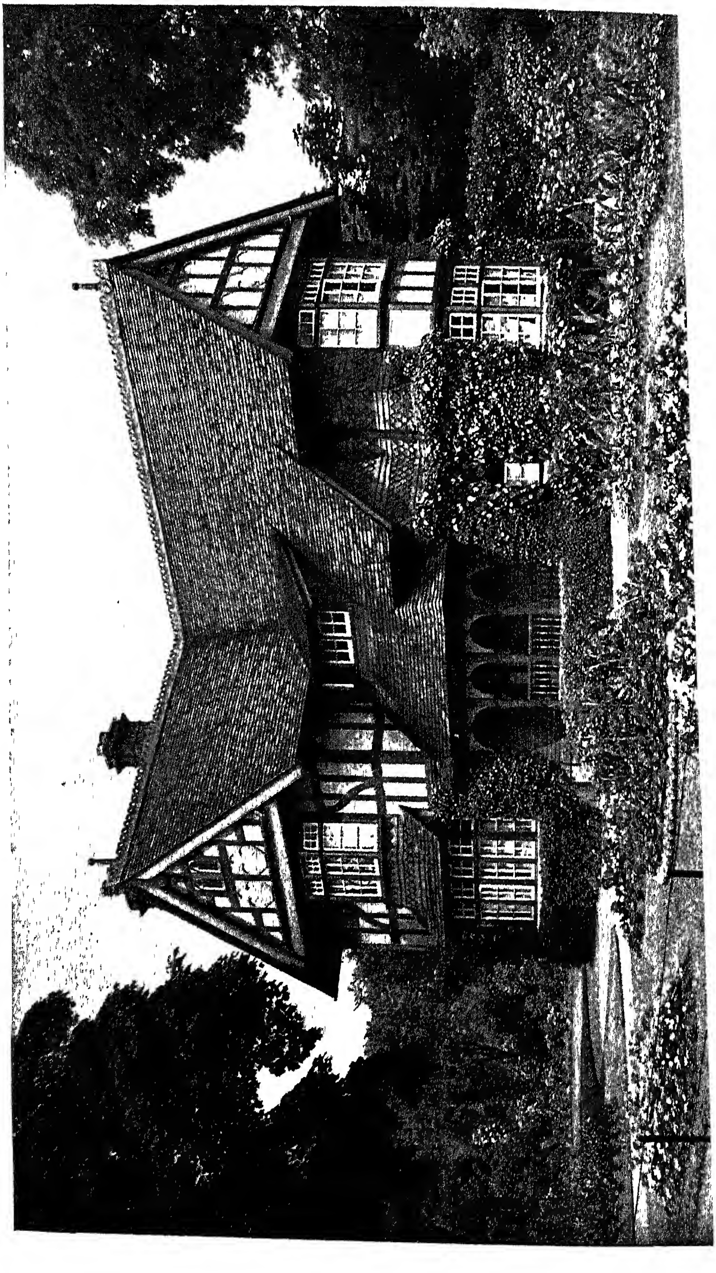


Fig. 20.

The curve in Fig. 20 is like a logarithmic line, in which the subjective luminosity increases in logarithmic progression with increasing objective luminosity.

A grey, for instance, composed of 3·5 parts of white and 6·5 parts of black appears to our eye twice as bright as it ought to appear, and we are only impressed by one-fourth of the amount of the black which is present in a grey composed of equal quantities of black and white. It is possible that similar phenomena are noticeable in mixtures of black with other colours, but it will be necessary to ascertain to what extent the law is influenced by the luminosity of the other colour. Moreover, such considerations are of great importance for all colour mixtures, because only a part of the black contained in the pigment is actually perceptible.

The previously mentioned green G made from Prussian blue and chrome yellow contains about 3 to 5 parts of black. If our mental colour sensation would follow the mixing laws we could only perceive a grey of a greenish tint, but as the presence of 60 per cent. of black does not yield a subjective luminosity of 0·4, but of 0·8 the black sensation is so much diminished that the green appears fairly pure. Colour mixtures of pigments appear therefore purer in hue than they are, without which peculiarity of vision the technic of painting as well as that of colour printing would be an impossibility.



PART II.

THEORY AND PRACTICE OF THREE-COLOUR PHOTOGRAPHY.

A. THE THEORETICAL BASIS.

THE assumption of a trichromatic composition of all body colours leads to a very simple theory of three-colour photography: Analysis of the colours of the original into the three primary fundamental colours by photographic means, and synthesis by means of these fundamental colours. The photographic analysis furnishes us with three ordinary negatives, which serve for the production of monochrome copies, and these may be combined by means of projection, reflection, or superposition on paper.

The analysis and synthesis of colour requires, therefore, well-defined colour elements, which permit of no variation.

For the purpose of photographic decomposition the original is photographed three times by means of colour filters, which only permit the passage of one spectral section, absorbing the other two. The division of the spectrum into three parts has been discussed on page 55, but we have to remember that a sharp division by means of colour filters is not possible. The nearest approach is defined in Fig. 16, page 56. Although such filters do not show abruptly terminating absorption bands, they are, nevertheless, suitable for our purpose because, if we

assume three spectral sections as undividable units, it is immaterial whether the whole or only part of such a section is photographically active, this only influencing the length of exposure.

1. The Theory of Colour Reproduction.

The densities of the three negatives taken through the colour filters represent the amount of red, green and blue light reflected from the original, and prints made from such negatives in three colours give, when superimposed, the original colours. The most usual way of recomposition is by means of diapositives, which are backed with red, green and blue glasses and are superimposed by projection.

The colour picture of the Photochromoscope is obtained in a similar way.

The projection filters should be the same as those used for the taking of the negatives.

In practical work, however, a difficulty is encountered, because the projecting filters must, when superimposed,

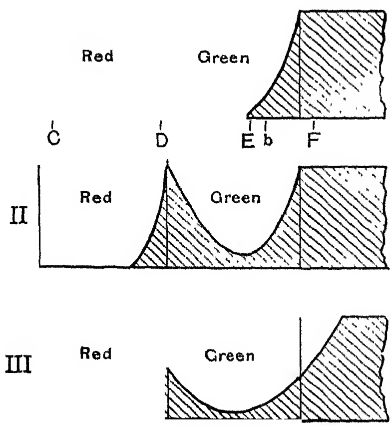


Fig. 21.

form white, which is a condition not fulfilled by the taking filters (see page 56). We are forced, therefore, to use a

different filter set, comprising a deep red, a whitish green and a blue, which selection accounts for certain deficiencies in the colour reproduction. A yellow part of the original for instance, reflects according to absorption spectrum I., Fig. 21, the entire red and green rays, and is reproduced by superposition of the rays transmitted by the red and green projection filters.

If we use for projection the taking filters, Fig. 16, we can only get an orange II., because the red filter transmits more rays than the green. To reproduce yellow, a whitish green filter III. is required for projection, and a yellow is obtained which is somewhat whitish when compared with the original.

Infinitely more favourable are the conditions of three-colour screen photography, because taking and reproducing filters are the same.

The filters, in this case, are formed by lines or minute dots, and the adjustment of the three elements to recompose white or neutral grey is possible by increasing the red or blue elements.

THREE-COLOUR PRINTING.

Another method of three-colour photography depends upon the superposition of transparent pictures, made from trichromatic negatives. Such pictures have to be printed in the colours blue-green, magenta-red and yellow, as explained previously.

The negative produced with the red filter, represents in its densities the amount of red reflected from the original, and in its transparent portions parts of the picture not reflecting red. To reproduce such colour characteristics on paper it will be necessary to print in blue-green colour, which reflects no red rays. The same considerations hold good as far as the other two colours are concerned.

It is immaterial what method is employed for the production of the component pictures; they can be made photographically by means of the carbon process or by

printing on the press, but the colours must always be identical with the three secondary fundamental colours.

The whole process is theoretically as correct as the projection method, and allowing for the shortcomings of the red and blue pigments there is no justification for the incorrect colour reproduction so often met with. The real difficulty is found in the production of the printing plates, not in the principle of the method.

The photo-mechanical method at present in use suffers from gradation defects which are not very noticeable in monochrome reproduction, but gives in trichromatic superposition false colour mixtures.

THE PRINTING INKS IN THEORY AND PRACTICE.

The imperfections of printing inks have a peculiar influence upon the practice of three-colour printing, because they form the reason why it has not been possible to succeed with theoretically correct printing inks. Although we have now approximately correct inks at our disposal—inks which are also fairly permanent—the practical man prefers to use the old inks and not without good reasons.

The printing inks of theory are so very bright and fiery, that to reproduce the hues and shades of all body colours two colours are nearly always required to give the hue, and the third to furnish the necessary amount of black, all three colours coming into play. Such a colour scheme construction is naturally very sensitive and the slightest error in the balancing of the pigments makes it impossible to reproduce neutral grey or black.

The practical man also objects to the insufficient covering power of the theoretical inks, which according to his views injures the neutrality of the shadows, but this is really caused by the imperfect rendering of tone gradations by photo-mechanical processes. Under these circumstances better results are obtained by using a pure yellow, a deep, almost blackish blue and a very deep red, because

slight differences in the depth of the single prints or defects of printing forms do not greatly influence the result.

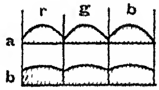


Fig. 22.

Fig. 22 shows the spectroscopic composition of a grey by both colour combinations. Theoretical printing inks give the grey *a*. Every alteration in the intensity of one of the colours must materially alter the result, because the absorption of one spectral section is only affected. The absorption curves of the usual printing colours, however, are gradual and overlapping, forming grey *b*. If we alter the intensity of one of these colours, we affect the absorption curves of all three and the colour balance is not greatly influenced.

Another great advantage of the permanent printing colours is that several colour mixtures can be formed by two components only. The blackish green, for instance, a very important colour in landscapes, is evidently more easily composed of a blackish blue and yellow than of yellow, red and blue-green.

Of course, the red plate requires correction in this case, because the blackish green is photographically decomposed into blue-green+yellow+red, and if we use a blackish blue in the place of blue-green, further addition of red is not required.

To reproduce pure and very brilliant colours is not possible with the theoretically incorrect inks, but we rarely find very brilliant greens or violet, or pure blue-greens, or magenta colours in nature, excepting flowers, exotic butterflies or silk colours, which are not of great importance in everyday life. Even the artist uses blackish colours only, and the colour magnificence of a painting is not due to the use of brilliant pigments, but to the effects of colour contrast.

Fig. 23 shows the colour triangle into which the usual printing colours have been introduced. Colours outside the curve *K K* are of minor importance, and as far as three-colour printing is concerned, only colours enclosed within the curve are to be considered. There is no difficulty in

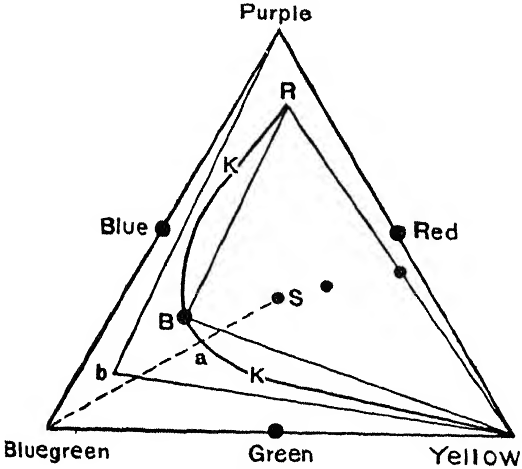


Fig. 23.

finding a perfect yellow; colour *b* represents a printing ink which is nearest to the ideal blue-green (blue No. 5514, Kast & Ehinger), and red is represented by red No. 5971 of the same firm. These three printing inks are fairly permanent, and may be considered as forming a "theoretically correct colour system."

We use, however, for the above-mentioned reasons, in the place of the blue-green *b* a darker, less greenish blue, similar to Prussian blue, and a red represented in R (red No. 1511, Kast & Ehinger). With these three colours, which one may term "practical colours" we construct the triangle yellow, R, B, which does not enclose all the important colours contained within the curve *K*, but sufficient to meet practical requirements.

Fig. 23 shows that blue *B* preserves the purity of green and violet colours better than a mere blackish blue, as for

instance, that of point *a* would do, which would give better greens, but very impure violets.

Colour Supplement I. shows both colour systems, and the resulting colour mixtures. Both systems give black. The theoretical inks require very careful adjustments, and the practical inks a very intense impression of blue. The colour triangle, Fig. 23, teaches us that two units of B Prussian blue are required to be mixed with one unit of yellow and one of red to give a pure black, and also that if the blue impression is too light we obtain a reddish brown situated in *s*. Retouching of the red negative, however, will in most cases ensure a neutral grey.

PRINTING INKS AND THE DETERMINATION OF THE PHOTOGRAPHIC ANALYSIS OF COLOUR.

The above observations seem to prove that the colour system based on the "practical" inks requires considerable retouching of the negatives, which is directed towards a weakening or total elimination of parts of the red component.

The question naturally arises, whether this defect cannot be overcome by a suitable readjustment of the trichromatic components. Considering the trichromatic composition of all body colours, this question must be answered in the negative.

It is a mistake to assume that each and every colour can be isolated by means of a colour filter, that, for instance, orange can be isolated by an orange filter.

If we take orange to contain one part of red and ½ part of green, the photographic plate should, therefore, be acted upon by one part of red and by ½ part of green. It is impossible to fulfil this condition, for not only may this colour contain no green at all, but the filter will transmit the whole of the green in the picture regardless of proportion to the red.

The isolation of a colour component by means of a light filter may be taken as a criterion of its usefulness.

Every filter should render its own body colour as light as white itself.

This is actually the case, when we deal with red, green or blue filters. Moreover, an orange-coloured filter would render the colour orange darker than white, because the latter acts with $1\frac{1}{2}$ intensity units (1 red+$\frac{1}{2}$ green), the latter only with $1\frac{1}{4}$ because the filter permits only of the passage of one-half of the green rays present.

The modification of the colour filters necessitated thereby is only possible in an empirical way, and will be discussed later.

FOUR-COLOUR PRINTING.

The above considerations appear to suggest that three-colour printing is by no means a perfectly straightforward process, and that a good deal of manual labour is required to get over a variety of difficulties encountered in practical work.

The means at our disposal are not delicate enough to permit of a strictly systematic trichromatic synthesis, and the use of incorrect fundamental colours and considerable retouching has to aid us in arriving at satisfactory results.

Another method of meeting this difficulty is based upon the reproduction of colour hues by means of the three colours and of the shades by using a fourth colour, grey or black. We obtain in this way perfectly neutral tones, and as all colour hues can be reproduced by pairs of the trichromatic fundamental colour, we encounter no difficulty in reproducing greys, blacks or colour mixtures containing same. This process, therefore, requires a fourth printing negative, and the elimination of everything contained in this negative in the trichromatic negatives.

Dr. E. ALBERT eliminates the black or grey picture element in the following mechanical way.

Consider I., Fig. 24, to be the original consisting of red, green and blue squares separated by a black band *s*. If photographed behind a red filter we obtain a negative II. The red field will show a dense silver deposit, and the blue, green and black fields will be transparent.

A negative for three-colour printing must, however, eliminate the black band, because this black is to be formed by a separate impression. To do this, we photograph the original with a panchromatic plate, which is sensitive to all three spectral colours and we obtain negative III. from which diapositive IV. is made.

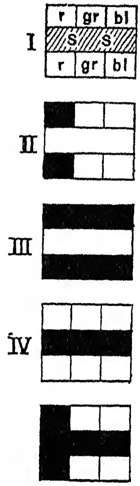


Fig. 24.

This diapositive is combined with negative II. film to film in perfect register. The combined plate is illustrated in V. and answers to the requirement of the red screen negatives for four-colour printing, but is useless for printing purposes, because it is composed of two glass plates. It is necessary therefore to make a camera diapositive and from that another negative.

The other two negatives are treated in a similar way and we obtain three negatives of the three-colour impressions and the panchromatic negative represents the black component. Only theoretical printing inks can be used in this process, because the other colours contain too much black.

This process is extremely ingenious and theoretically perfect, but is very costly on account of the amount of expert labour involved, and, moreover, is very delicate to apply in practice. The process is very little used, and the usual method of eliminating the black by means of retouching is generally resorted to, in which case the ordinary printing colours may be used.

Supplement I. shows an example of the synthesis of colour by means of three and four-colour photography.

It is assumed that green G g, Supplement II., is to be reproduced. According to its position in the colour triangle, this green is composed of two parts of green and three parts of black, which corresponds to our representation of the colour in Supplement I.

In three-colour photography this green may be formed in two ways. We can use the usual printing inks, Milori blue and yellow, or the theoretically correct inks. The photographic analysis furnishes negatives suitable for the second method. If we print with the usual printing inks we must eliminate the red altogether, because the green would be too impure, but if theoretical inks are used the red is absolutely necessary, otherwise the green would be too bright and not impure enough.

In the four-colour process this brilliant green of two theoretical inks is made impure by the fourth plate, which is black, the proportions being as follows :—1 part blue-green+1 part yellow+3 parts black.

2. The Young-Helmholtz Theory as the Foundation of Three-colour Photography.

In addition to the above-mentioned theory, which was first established by the author, another theoretical foundation was enunciated by using the Young-Helmholtz theory of colour vision.

As explained on page 28, the various coloured rays excite a stimulus of three groups of nerves contained in our organs of vision, which transmit such colour sensations to the brain. The three photographic plates used in three-colour photography correspond to the three groups of nerves, the coloured light in one case producing chemical action, in the other colour sensation. If we transform the result of this chemical action into coloured light of such constitution as to incite a stimulus of one of the three nerve groups, we find that the sum of such lights excites exactly the same sensations as the original coloured light.

To ensure similarity of action it is requisite :—

1. That the colour sensitiveness of the photographic plate shows a similar curve to that representing the elementary sensations of our eye.

2. That the reproduction colours correspond to the three primary colour sensations.

We obtain apparently well-defined fundamental laws for our guidance in three-colour photography, which when applied to practical work prove to be of no value at all. Different colour triads may answer the conditions of recomposition to white, and all such colour triads will be suitable for the reproduction of all body colours, provided they are of sufficient saturation. It is clear, however, that the colour triad red, green and blue meets this condition better than any other, but considerable differences exist in the colour triads selected by various experimenters. The red selected is generally the extreme red of the spectrum, although a magenta, not present in the spectrum, has been selected (F. Exner) ; the green varies between yellow green $\lambda = 540$ (Helmholtz) and blue-green $\lambda = 505$ (König & Dieterici), the blue between a greenish blue $\lambda = 482$ (Grünberg) and a pure blue and even a violet.

We see, therefore, that three-colour photography cannot rely upon the Young-Helmholtz theory for the selection of the fundamental triads. Moreover, the absorp-

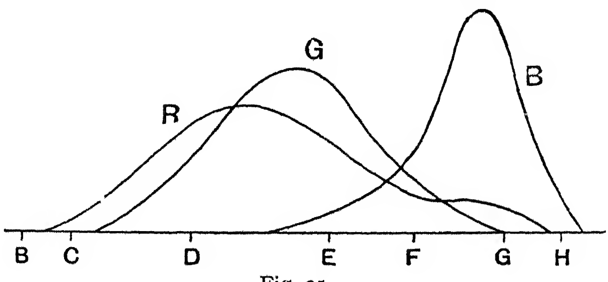


Fig. 25.

tion curves of the filters depend upon the establishment of the primary colours, which theory has not established yet.

A little consideration will show that such filters could never be used for trichromatic analysis.

According to the curves established by König and Dieterici and illustrated in Fig. 25, the red curve R would require a filter transmitting yellow, orange and yellow-green rays, very little red and green, but all the violet rays.

The colour of such a filter, made by mixing Naphthol-green with orange, would be yellow-brown and the use of such a filter in trichromatic analysis would be absurd.

We do not assert that this deduction derived from the Young-Helmholtz theory of colour vision is incorrect, but it can only hold good if the physiological fundamental colours of a high saturation are inserted as factors—colours existing in theory only.

THE MAXWELL CURVES.

Much nearer to practical requirements is the selection of fundamental colours, capable of reproducing the hue of all other spectral colours, as defined by Maxwell's curves.

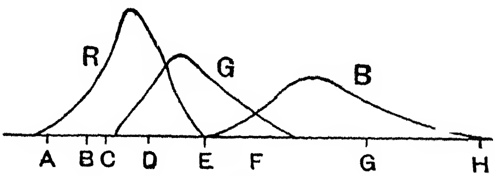


Fig. 26.

MAXWELL selected the following wave lengths as representing the fundamental colours. $\lambda = 630$, 528 and 457 $\mu\mu$. With these three colours he endeavoured to reproduce all other spectral colours and obtained a result illustrated by the curves of Fig. 26.

The intensities of the fundamental colours are given as ordinates and the slope of the curves shows that, for instance, the recomposition of the colour of the D line requires about equal parts of green and spectral red. It must be admitted that several of the other spectral colours cannot be reproduced without loss of saturation, which is most noticeable in the blue-green.

Although König and Dieterici's curves have never played a part in colour filter making, those of Maxwell are frequently recommended, but have never been made use of in practice.

The reason is found in the fact that the curves are based upon spectral lights, whereas practical three-colour photography deals only with very whitish lights of infinitely less purity.

If we assume, for instance, that a colour filter transmits all the rays of the green spectral section, our diagram shows that such a colour complex may be reproduced by mixing red, green and blue spectral fundamental colours. If we use, however, in the place of the fundamental colours, which are spectral lights, ordinary red, green and blue light transmitted by the usual colour filters, the resultant green will not be pure enough and the red and blue components will appear very undesirable; and this holds good with all colours.

The Maxwell curves embrace $\frac{1}{2}$ to $\frac{2}{3}$ of the spectrum and are represented by whitish filters, which in the case of subtractive recomposition give a blackish, and in the case of additive synthesis give a whitish, colour reproduction

THE RELATION BETWEEN PRINTING INK AND LIGHT FILTER.

The seemingly intimate connection between printing colour and light filter has often been made a leading principle in three-colour printing and Cross and Ducos du Hauron based their experiments upon this principle. As taking filters, a green, blue and yellow were selected and the negatives were printed in the complementary colours red, yellow and blue.

Until recently this principle has found much favour and Hazura and Hruza made a series of experiments to find complementary light filters to given printing inks. The condition that light filters and printing ink should be complementary is theoretically quite correct, but we

must not be led to believe that it is possible in this way to get three-colour negatives for any method of projection or trichromatic printing.

Photographic analysis of colour is only possible by splitting the colours into the three fundamental colours composing white light, and we have shown on page 39 that it is impossible to isolate the orange components of a picture by means of an orange filter, and that no benefit can be derived in practice from the condition that the colour filter must be complementary to the printing ink.

Another important condition is that the absorption spectra of filter and ink are to show similar curves. If I., Fig. 27, represents the absorption of the printing ink, II. should represent the complementary filter.

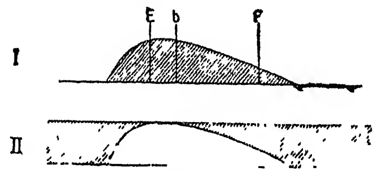


Fig. 27.

This condition cannot be fulfilled, however, because we cannot model the absorption curve of a filter to accurately fit that of the printing ink. The absorption bands of aniline dyes are very indefinite, and we must be satisfied to approximately isolate the three principal spectral sections.

B. THE COLOUR SENSITIZING OF PHOTOGRAPHIC PLATES. THE LIGHT FILTERS.

The ordinary photographic plate is generally called blue sensitive, because short exposures show, after development, visible action of the blue and violet rays only. If exposure is prolonged, the green, the yellow and finally also the red rays exert chemical action. A photograph of the spectrum extends, when short exposure is given,

up to line F, with long exposure the band widens towards the red end.

The curves of sensitiveness of bromide of silver are given on the prismatic spectrum in I. and II., Fig. 28. I. corresponds to gelatine, II. to collodion emulsions. The first is chiefly sensitive to rays between G and H, the second to violet rays of the spectrum.

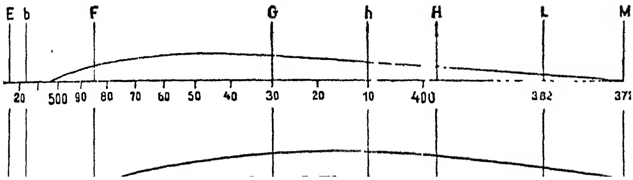


Fig. 28.

This difference, however, is not noticeable in photographic three-colour work, and can be easily corrected by adjusting the blue filter.

A body which appears blue, reflects the rays of the entire blue spectral section and it is almost immaterial whether the greenish or the reddish end of the blue section acts photographically.

The photographic plate, however, is sensitive to rays belonging to the invisible part of the spectrum, the ultra-violet rays, and it is of importance to study the influence of such rays.

According to Dr. J. M. Eder the importance of these rays in the production of photographic images has been greatly exaggerated Daylight has very little of these rays in its composition, and the glass of photographic lenses and filters absorbs ultra-violet light. Most bodies, moreover, absorb ultra-violet rays and very minute quantities will be found in the light reflected from them.

Ultra-violet light is almost without influence upon the photographic reproduction of colours if the exposures are normal, and experiment shows that, for instance, the colour chart on supplement I., if reproduced with a filter transmitting ultra-violet light only, is identical with a

reproduction of the same chart made with a blue filter, which absorbs ultra-violet light completely.

1. The Colour Sensitizing of Photographic Plates.

The addition of suitable dyes to the bromide of silver greatly increases the sensitiveness of a photographic plate for the less refrangible rays of the spectrum and spectrographs record, besides the usual band in the blue-violet, another band in a part of the spectrum nearer the red.

The sensitiveness of such colour-sensitized plates does not terminate abruptly. Short exposures show an abrupt maximum, which terminates gradually when exposure is increased.

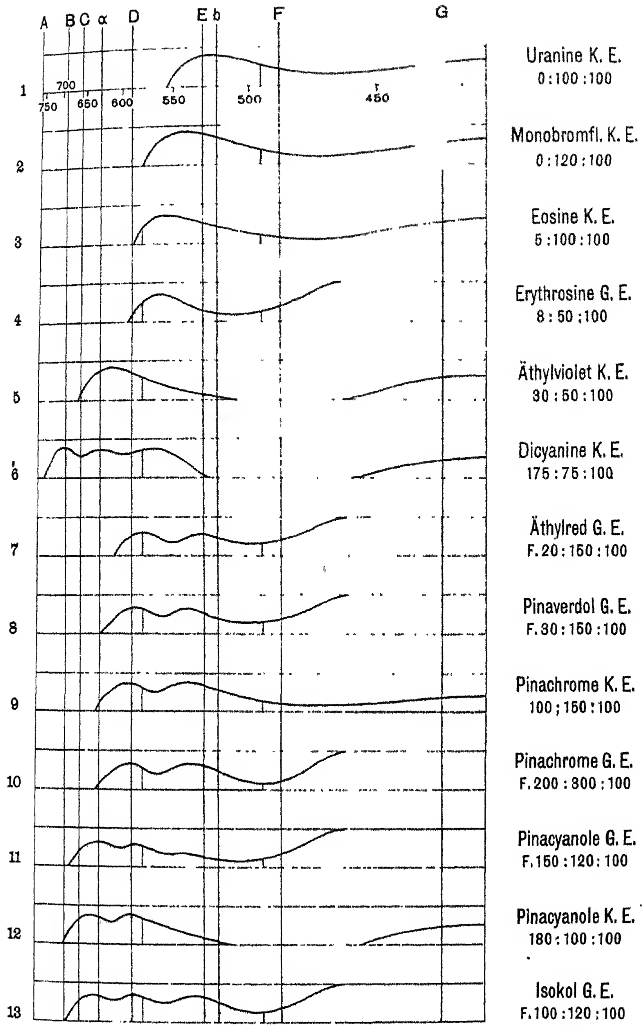
PECULIARITIES OF COLOUR-SENSITIVE PLATES.

To ascertain the colour sensitiveness of a photographic plate we photograph the spectrum and estimate the sensitiveness by the densities in various parts of the spectrum negative.

For accurate work it is necessary to measure the densities with the aid of Marten's Polarization Photometer, and to construct a density curve. If we insert on a wave length scale the densities as ordinates, we obtain a curve which represents a section of the negative, called a density curve, or in the case of colour-sensitive plates a curve of sensitiveness. The unit for measuring the ordinates is the thickness of a film transmitting $\frac{1}{10}$ part of the light only.

Curve K in Fig. 29 shows the spectral density curve of a yellow-green sensitive gelatine plate of Lumière, being colour-sensitive between D and E *b*, and recording a density 0·8 in the green and 2·5 in the blue section of the spectrum.

The surface enclosed by curve K corresponds to the total amount of reduced silver and as the straight line A near $\lambda = 495$ forms the limit between the green and blue section, the proportion of the silver deposits of the two sections is as 1 : 3.



colour photography.

Other deductions, however, especially those referring to the reproduction of coloured objects, are of very doubtful value.

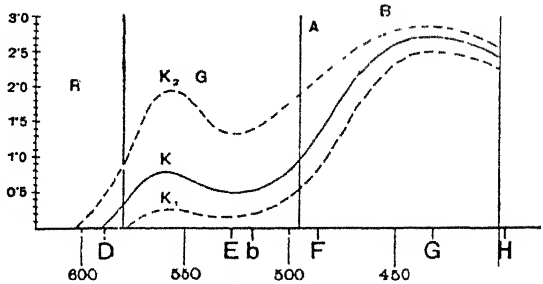


Fig 29

If we photograph the spectrum giving short and long exposures, we get the curves K1 and K2, which seem to indicate that the green sensitiveness of the plate is not a constant, but increases with increase of exposure.

This corresponds to the well-known fact that the colour sensitiveness of a plate is most pronounced when the exposures are very full, but the three curves give no indication as to which one corresponds to the conditions of photography of coloured objects in the camera. This spectral curve of sensitiveness is chiefly of theoretical value, permitting conclusions as to the nature of a sensitizer, the identification of plates of various manufacture, but is of no practical value beyond giving us a curve showing qualitative behaviour of a plate towards the spectrum.

Supplement III. shows a series of such curves, which will be discussed later on.

THE PRISMATIC AND THE DIFFRACTION SPECTRUM.

The shape of the density curve depends chiefly upon the constitution of the spectrum, and will be different with prismatic or diffraction spectra.

The diffraction spectrum shows almost equal division of red, green and blue, but the prismatic spectrum gives

narrower red and green bands which are more brilliant because the rays are more concentrated, being confined to narrower spaces and acting with greater intensity upon the photographic plate.

It is comparatively easy to judge as to the suitability of a plate for trichromatic work by using the diffraction spectrum, because the spectral sections are of almost equal width and should, therefore, correspond to the densities produced by a red, green and blue object when photographed. The diffraction spectrum, however, is of poor luminosity when compared with the prismatic spectrum and this may account for the insufficient record of the red sensitiveness of a plate when diffraction gratings are used.

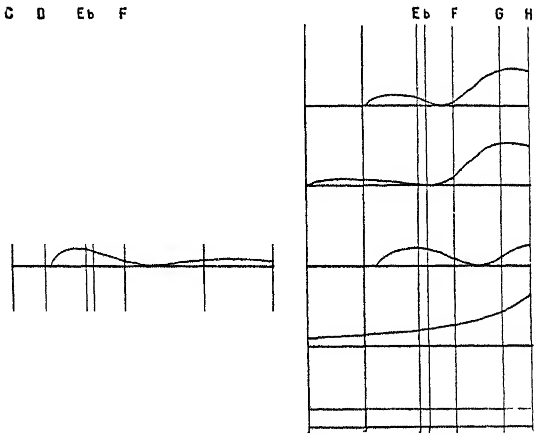


Fig 30

The following examples will illustrate considerable differences between the two spectra and their action upon photographic plates.

Curve A, Fig. 30, represents a gelatine plate sensitized with Erythrosine. According to the prismatic spectrum curve we expect equal sensitiveness for yellow, green and blue, whereas the diffraction spectrum curve shows a very limited sensitiveness for yellow-green. Curve C shows

a gelatine plate of apparently great red sensitiveness when exposed to the prismatic spectrum, and very little red sensitiveness when exposed to the diffraction spectrum.

This plate, if used without a filter on a coloured original, actually exhibits no red sensitiveness at all. The collodion emulsion plate *c* sensitized with eoside of silver, if judged by results obtained with the prismatic spectrum, shows sensitiveness for yellow-green only, whereas this plate does not render yellow-green pigments lighter than blue pigments, which corresponds to the curve of the diffraction spectrum. Plate *d*, showing in the prismatic spectrum curve equal sensitiveness to all rays, would, according to the diffraction spectrum, record red objects as black, being insensitive to red rays. If equally pure and saturated colours are to be rendered equally light the plate must be equally sensitive to all rays of the normal spectrum, which is illustrated by a curve which is almost a straight line, and which is equivalent to curve *c* of the prismatic spectrum.

For practical experiments the prism spectrograph of Vogel is quite suitable, and the density curves of Supplement III. have been ascertained by means of this useful little instrument.

For scientific purposes the diffraction grating is generally used. A transformation of the curves of the one into those of the other is possible, but is always connected with considerable errors.

THE COLOUR CHART.

Another way of ascertaining the colour sensitiveness of a photographic plate is by means of the colour chart.

It is advisable to select the fundamental colours, red, green and blue, which have been reduced to equal luminosity. These three colours form the elements of all colour composition and they are to be photographed with the plates which are to be tested. The densities of the three-colour surfaces in the negative characterize the sensitiveness of the film for rays of the three spectral sections.

Only in this respect has the quotation of speed numbers a practical value.

If we characterize, for instance, the colour sensitiveness of a plate by a ratio 1 : 3 : 10, we mean that the plate represents red, green and blue fundamental colours in the above luminosity ratio.

There is no query as to the exposure in the camera once this ratio is established, and a grey scale is not absolutely necessary, though advisable.

A very useful form of colour scale, which shows the colour-sensitiveness of a plate at a glance is given in Fig. 31.

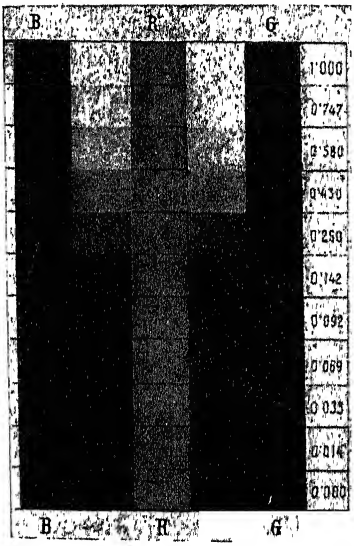


Fig. 31.

This scale consists of ten gradations of a grey scale and three bands of red, green and blue paper, R.G.B., which correspond to the fundamental colours.

The luminosities of the grey scale are determined by colour top experiment and are inserted at the right-hand side of the scale.

If we photograph this chart with a colour-sensitive

plate and compare the densities of the coloured strips of the negative, or the copy, with the three on the chart, we find the luminosities with which the three fundamental colours were reproduced. Fig. 31 shows a reproduction made with a very red-sensitive plate.

The density of the red band lies between 0·43 and 0·25 and is equivalent to the density of grey 0·34, green and blue correspond to grey 0·10 and 0·12. The ratio of sensitiveness for the three colours is, therefore, 1 : 0·3 : 0·36, and we may conclude that this plate photographs vermilion coloured objects about three times as light as green or blue ones.

The colour sensitiveness of ordinary gelatine dry plates is generally so very low that it is necessary to use a light yellow filter (filter yellow 1·0) to ascertain the ratio red : green.

THE REPRODUCTION OF COLOURED BODIES.

If the colour sensitiveness of a photographic plate is known, there is no difficulty in stating the luminosities with which all pure and saturated body colours will be represented. For the purpose of graphic representation it is only necessary to imagine the colour circle to be stretched

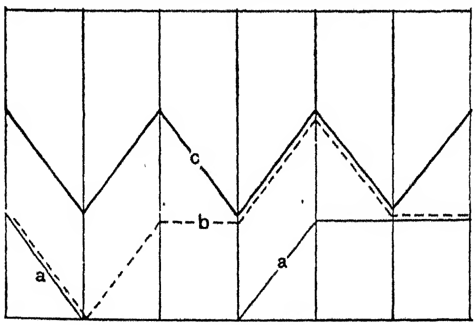


Fig. 32.

into a straight line, Fig. 32, and the luminosities with which the three colours are reproduced inserted as ordinates.

The system *a. a.* corresponds to a blue-sensitive plate,

because the body colours blue, blue-green and magenta appear equally light on account of total reflection, and the colours between red and green are rendered as black.

According to the maximum in yellow, we expect this plate to render yellow pigments darker than red ones.

White is reproduced like light blue, because even in white light only the blue component rays are chemically active.

A plate sensitive to blue and green is represented by the line *b*. Blue-green and white are rendered twice as light as yellow, green, blue and red, and only the vermilion is photographed almost black. Such plates are called orthochromatic, because they enable us to photograph all colours except red correctly according to their luminosities. A photographic plate sensitive to all these colours is called "panchromatic," but the ratio of sensitiveness need not necessarily be 1 : 1 : 1.

By using a properly adjusted filter such plates can be made "isochromatic," which means that they are equally sensitive to all three colours as shown in line C, Fig. 32.

Yellow, blue-green and magenta, which are composed of pairs of fundamental colours, are to be rendered twice as light as red, green and blue. White formed by all three components must be rendered three times as light.

If we consider the constitution of body colours we understand why all pure colours cannot be photographed equally light. Yet pure blue-green and magenta are rarely found in nature, and as most colours are more or less shaded by the addition of black, we may consider the statement fairly correct that isochromatic plates render all pure body colours equally light.

The Sensitizers.

As white light is only composed of red, green and blue rays and the photographic plate is in itself sensitive to blue rays, we can only discuss the sensitizing of a photographic plate for red or green light. To sensitize a plate

for yellow only is not possible, because so-called yellow sensitizers cause considerable red and green sensitiveness, which is also the case with the so-called blue-green sensitizer.

If our assumption of a division into three constant spectral sections is upheld, it will be immaterial whether we sensitize a plate for the blue green or the yellow-green and of the green section, or whether the plate is made sensitive to all the green rays comprising the entire section. The curve of sensitiveness of a green-sensitized plate, for instance, is never abrupt, and extends more or less over the whole section, ensuring equal exposure for all green body colours between blue and green, regardless of the sensitizing maxima. The same refers to the red sensitizers and we come to the very important conclusion that it is only necessary to make the photographic plate sensitive for part of a particular spectral section, and not for rays of the entire section.

GREEN SENSITIZERS.

A colour sensitizer showing a marked sensitizing maximum in the blue-green between lines E and F has not been discovered up to the present, and would be really of little value except for spectroscopic research.

The often-expressed view that blue-green objects cannot be photographed light enough, because we do not possess a blue-green sensitizer, is altogether wrong. The real reason is found in the impure blue-green itself, which contains a high percentage of black, and which cannot photograph as light as really pure blue-green.

There is no need to search for special blue-green sensitizers for three-colour work, because a plate sensitized for blue and green fully answers the purpose. Excellent sensitizers for green are the aniline dyes Uranine and Mono-bromo-fluoresceine of sodium, which may be used as silver compounds with collodion emulsions (see Figs. 1 and 2, Supplement III.).

The colour chart records the following ratio of colour sensitiveness between red, green and blue 0 : 100 : 100, showing that emulsions sensitized with either of the above dyes have excellent green and blue sensitiveness and no red sensitiveness at all.

The Eosines, especially when used as silver compounds, form excellent sensitizers for yellow-green. Collodion emulsions are generally sensitized with the yellow Eosine (tetra-bromo-fluoresceine of sodium), and gelatine emulsion with the iodine compound of the same dye. Figs. 3 and 4 give the respective curves, which record a very slight red sensitiveness.

RED SENSITIZERS.

Not until the advent of three-colour photography was it found necessary to search for red sensitizers, because the green-sensitive plate was sufficient to meet the requirements of orthochromatic photography.

The first sensitizer used was the Cyanine, which proved very unreliable, giving spots, fog and general lack of density in the negatives.

Ethyl-violet, recommended by E. Valenta, proved, however, an excellent red sensitizer for collodion emulsion, perfectly free from all the defects of Cyanine, and represented by curve Fig. 5. The ratio of colour sensitiveness is 30 : 15 : 100, which means a slight green sensitiveness, which is characteristic of all red sensitizers.

Ethyl-violet has found little use in the sensitizing of gelatine plates, because shortly after its discovery a series of dyes belonging to the Cyanine group were introduced and proved in every respect satisfactory.

Dicyanine sensitizes even for the infra-red of the spectrum, but it is only suitable for collodion emulsions. Fig. 6 shows the curve of sensitiveness of this dye, and the ratio of colour sensitiveness according to the colour chart is 175 : 75 : 100.

RED-GREEN SENSITIZERS.

In addition to the above-mentioned Dicyanine, a number of other cyanine compounds have been discovered, which are much more important and which have brought about the great strides of colour photography within the last few years.

They sensitize almost evenly for red and green and they enable us to prepare panchromatic plates of very high speed.

The first panchromatic sensitizer was Dr. Miethe's Ethyl-red, which did not show very great red sensitiveness, but which served as a valuable guide in the researches of Dr. E. König, and led to the discovery of a series of sensitizers now in general use.

Curve 7 shows the action of Ethyl-red and the ratio of colour sensitiveness is* F 20 : 150 : 100. Curve 8 represents Pinaverdol, which, like Orthochrome, may almost be called a green sensitizer.

A sensitizer giving almost equal red and green sensitiveness is Pinachrome, which can be used with collodion emulsions and gelatine plates. Collodion emulsion sensitized with this dye is almost panchromatic without a filter, and gelatine plates require a light yellow filter only (Filter yellow 0·6).

The sensitizing curve of Pinachrome, Fig. 10, is not very different from that of Fig. 8, representing Pinaverdol, yet both sensitizers show very different behaviour as sensitizers for body colours.

The Pinachrome plate gives red and green in proportion 1 : 1·5, but the Pinaverdol plate in proportion 1 : 5. And again, we note how very unreliable are conclusions derived from spectral observations only.

Another panchromatic sensitizer, which does not show great green sensitiveness and is generally used as a red sensitizer in collodion emulsions, is Pinacyanol.

* The ratio of colour-sensitiveness of this or any other gelatine plate has been arrived at by using a yellow filter, which is signified by the prefix F. (*vide* page 84).

Mixtures of various dyes are very little used at present, because nothing is gained by equal sensitiveness for all rays of the spectrum, it being sufficient to ensure equal intensity of action in all three spectrum regions.

For scientific purposes the use of a plate of even sensitiveness is requisite and Isocol is recommended for gelatine plates. This dye mixture is composed of Chinolin red and one of the cyanine derivatives and confers almost uniform sensitiveness for all spectral colours from red to blue (see Fig. 13). If used for the reproduction of body colour, however, Isocol sensitizes exactly as Pinachrome.

To obtain perfectly isochromatic collodion emulsion we mix Pinacyanol with Pinachrome and ensure thereby even sensitiveness to all rays of the spectrum.

METHOD OF SENSITIZING PHOTOGRAPHIC PLATES.

Both collodion emulsion and gelatine emulsion can be sensitized before or after coating, and we differentiate between "bathed" plates and "colour-sensitized" emulsions.

Collodion emulsions are generally sensitized by adding the sensitizers to the emulsion, but the "flowing over" method is occasionally practised.

All dyes belonging to the Eosine group are used as silver compounds in collodion emulsion; the Cyanines, however, are used without further additions.

SENSITIZING OF COLLODION EMULSION PLATES.

We have three methods of sensitizing collodion emulsion with Eoside of silver.

(1) Add to every 100 cc. of emulsion 2 cc. of an alcoholic dye solution 1 : 150 (Eosine, Monobrom or Di-brom-fluorescin or Uranine) and bathe the plate after setting of the emulsion in a ½ per cent. silver nitrate bath. Expose wet.

(2) Sensitize the emulsion with a neutral solution of Eoside of silver in ammonia.

(3) Coat the plate with ordinary emulsion and flow diluted sensitizers (1 : 10 alcohol) over the plate, and expose.

To prepare such sensitizers we dissolve Eoside of silver, derived by precipitation from a mixture of Eosine and Silver nitrate, in alcohol and ammonia, and add for the purpose of neutralization Picric acid, until the first signs of precipitation are noticeable. Picrate of ammonia is formed, which stains the collodion film yellow and acts as a light filter.

The addition of this sensitizer not only confers upon the collodion emulsion green sensitivensss, but also increased general sensitiveness and other valuable photographic qualities, especially great clearness and good density of negative, which make it invaluable for screen negative making. For orthochromatic emulsions Eoside of silver is most suitable, but Mono-brom-fluorescin emulsions are best suited for trichromatic work.

If the sensitizer is added to the emulsion, the emulsion will not keep for more than a few days and has to be kept very cool, or fog will be the result.

The method of pouring diluted sensitizer over the coated plate or of using the silver bath is recommended as an alternative, but to save time and assure uniformity the first method of mixing sensitizers with the emulsion is generally practised.

To make collodion emulsion red sensitive or panchromatic, we use Ethyl-violet or the above-mentioned Cyanine derivatives. We add to every 100 cc. of emulsion

8 cc. of Pinachrome (Pinaverdol or Orthochrome).
or 2 cc. of Pinacyanol (Isocol or Dicyanine).
or 1 cc. of Ethyl Violet.
Solution 1 : 1000.

The coated plate is rinsed under the tap, which operation ensures considerable increase of sensitiveness. This phenomenon is peculiar to emulsions sensitized with the above dyes, and is probably due to a more intense coloration of the bromide of silver and a catalytic action of moisture

inducing the chemical reaction which takes place during exposure.

To obtain an isochromatic collodion emulsion we add to every 100 cc. of emulsion 10 cc. of a mixture of 50 cc. Pinachrome solution (1 : 1000)+10 cc. Pinacyanol solution (1 : 1000). The plate is washed before exposure, and shows equal sensitiveness to red, green and blue without any filter.

Collodion emulsions sensitized with the Cyanines lose their sensitiveness occasionally after a short time and a fresh addition of sensitizer is required.

Such emulsions work extremely clear, but soft, and are more suitable for continuous tone work than for half-tone. However, good screen negatives can be made with them, but a very hard working emulsion and a clever half-tone operator are required.

THE COLOUR SENSITIZING OF GELATINE DRY PLATES.

Excellent green-sensitive plates are on the market, and it is not advisable to sensitize dry plates in Erythrosine solutions, because such bathed plates are of bad keeping qualities and occasionally give foggy negatives.

To make red-sensitive or panchromatic plates, however, is by no means difficult. The following bath is used:

Water	120 cc.
Alcohol	50 cc.
Pinachrome (Pinaverdol or Orthochrome)	3 cc.*
Pinacyanol (or Isocol)	2 cc.*

*Solution 1 : 1000.

Time of immersion, three minutes. It is very important to dry the plates very quickly, as otherwise clear working plates cannot be obtained.

It is necessary to use the above-mentioned addition of alcohol to the bath, which greatly increases the colour sensitiveness. The reason for this is found in the imperfect solution of the dye in water. If the dye solution is filtered several times, the filtrate is almost colourless, the dye itself remaining in the filter. Very much the same happens when a gelatine dry plate is colour sensitized. The dye

itself remains on the surface of the plates without penetrating the film, causing spots, fog and streaks.

The colour sensitiveness of gelatine dry plates is very limited if compared with collodion emulsion. If sensitiveness for a definite spectral section is required gelatine dry plates always require a filter, but collodion emulsion will give perfect results without.

2. The Light Filters.

To exclude certain light rays from acting upon the photographic plate during exposure we interpose coloured media, known as light filters, in the path of light, either in front or at the back of the lens. The rays which are absorbed by the filter cannot act upon the plates. If we use, for instance, a yellow filter, which absorbs all violet and blue rays, we cannot get an exposure on a wet collodion plate, which is only sensitive to rays absorbed by the filter. On the other hand, if we use a blue filter which absorbs yellow rays during an exposure on a collodion emulsion plate unsensitized, no effect will be produced because the plate is not at all sensitive to yellow rays and it is immaterial whether they reach the plate or are absorbed by a filter. Coloured glass is very rarely used for light filters, because the absorptions are very indefinite. We generally use aniline dyes in solution or gelatine or collodion films stained with the dyes.

The absorptive properties of a dye depend upon the concentration. Weak solutions of Eosine, for instance, only absorb green rays, but concentrated solutions also absorb blue and violet rays. It is, therefore, not sufficient to name a dye; its concentration must also be quoted, as well as the media which are to carry the dye.

It is advisable to use the m^2 as unit of surface, and the gramme as unit of weight, when calculating the quantity required to obtain certain absorptions.

The same units can be used when we wish to describe the solutions for liquid filters. We quote the amount of

dye contained in liquid of 1 m^2 surface and 1 cm. depth, which corresponds to a quantity of 10 litres.

We have further to bear in mind that dry films and coloured liquids show slightly different absorptions. The absorption curves are generally similar, but the curves for liquids differ from 10 to 15 $\mu\mu$ towards the blue end of the spectrum. If a filter is open towards the red end of the spectrum, it will be necessary to increase the concentration of the liquid filter, but reduce it if the filter is open towards the blue end of spectrum.

A Tartrazine dry filter of density 1·0 is equal to a liquid Tartrazine filter of density 3·0. Due to the very impure nature of some aniline dyes which are often adulterated with dextrine and other compounds, great difficulties have been experienced in the manufacture of filters, but fortunately, at the instigation chiefly of Dr. E. König, the Höchster Dyeworks are now bringing chemically pure filter dyes* on the market, which are excellently suited for filter making, being of a very constant composition and carefully standardized.

THE FILTER DYES.

A very limited number of dyes are sufficient to meet all requirements of filter making.

Fig. 33 shows the absorption spectra of such dyes in gelatine films in two densities.

Yellow Dyes.—The yellow dyes absorb the blue and violet rays and their colour is due to a mixture of green and red light rays. The further the absorption band of such a dye extends into the green the more reddish is the yellow. Dyes with absorption beyond blue-green shows a more greenish hue, because their absorption bands are not very extended and all yellow dyes of a reddish hue permit the passage of ultra-violet light.

* *Vide* "The Photographic Light Filter," by Hubl. Published by W Knapp, Halle, 1910.

As a type of a greenish yellow we may name Filter yellow K, and of a reddish yellow Tartrazine.

Filter yellow is a very pure light yellow dye with absorption maxima in the ultra-violet beyond the H line. It absorbs all the ultra-violet which is photographically active, is permanent, very soluble in water, miscible with other dyes, and, therefore, a very valuable filter dye.

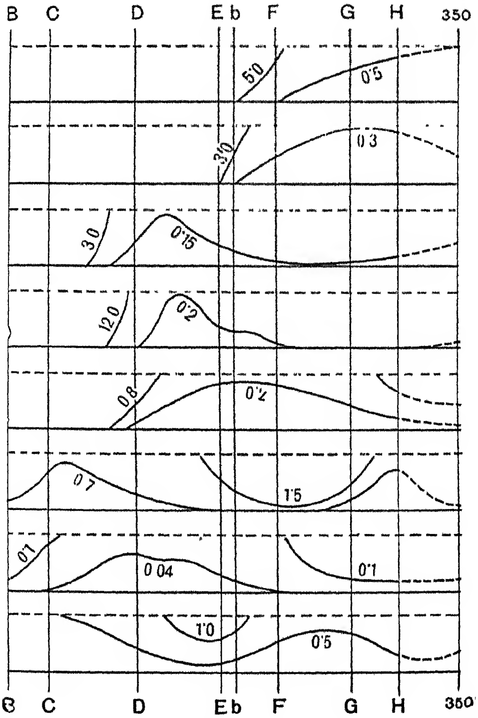


Fig. 33.

Tartrazine is a very pure yellow dye with a slight reddish hue and an absorption maximum extending over G H, transmitting ultra-violet, which can be avoided by adding Aesculine dissolved in ammonia. The absorption band of Tartrazine is nearer the red end, and it depends

upon the desired action of the filter whether Tartrazine or Filter yellow is to be selected.

For very thin filter films Filter-yellow is preferable; for thicker films Tartrazine, because a Tartrazine film of thickness 1 or 2 respectively is equivalent to a Filter-yellow film of thickness 8 or 20 respectively. The transmission of ultra-violet through dense films of Tartrazine is negligible in photographic work.

As the absorption curves of Tartrazine are more abrupt than those of Filter-yellow, the first named will be preferable for the making of green filters.

Red Filter Dyes.—Films stained with red dyes absorb all rays of the green spectral section, and often pass blue in addition to the red rays. According to such variations the transmitted light appears yellowish or bluish red.

For reasons explained on page 37 very thin filter dye films have almost always a bluish appearance, which gives way to a yellowish hue with higher concentration. Nearly all red dyes transmit ultra-violet.

Acid Rhodamine is a bluish red dye with strong fluorescence, passing all red and blue rays and showing, therefore, extremely brilliant colour.

The maximum is in the yellow-green. Nearly the whole of the pure blues between F and G are transmitted, and violet and ultra-violet are absorbed. Rhodamine is very suitable for very transparent red and blue filters, the latter passing no ultra-violet.

Rose bengal shows a very similar absorption curve in the green spectral section, but the absorption is slightly shifted towards the blue end.

The dye is, therefore, less bluish than Rhodamine and differs further by transmitting ultra-violet and violet rays. With increasing concentration the colour of the film becomes vermilion. Rose bengal is generally used for red filters on account of its permanency and its abrupt absorption towards the red.

Dianil red (Filter red I.) shows a broad, flat absorption band. If used in higher concentration this dye absorbs blue completely. It is a body of relatively impure colour.

Blue Filter Dyes. ·Films stained with blue dyes have a maximum absorption in the red or orange, appear in low concentration of a greenish hue and in higher concentration pure blue.

They often transmit red rays beyond the line C, which, on account of their low luminosity, do not affect the colour of the dye.

If the maximum absorption of a blue dye is in the yellow, red rays are more freely transmitted and the colour of the dye solution is of a violet hue.

Patent blue is a somewhat interesting dye on account of its absorption curves, which show a maximum in the red section and a minimum in the pure blue. The curve terminates abruptly towards the green, but not abrupt enough to ensure only absorption of the red section of the spectrum. Patent blue films up to 0·4 are blue-green, which colour changes to a pure blue with a higher concentration.

This dye is characteristic as a type of all blue-green pigments, showing distinctly that blue-greens of deep saturation do not exist.

Patent blue is used for the preparation of green filters in films 0·5 to 1·0 thickness. This dye almost absorbs the spectral violet and passes very little red, is permanent and miscible with other dyes. Mixed with filter yellow or Tartrazine we obtain a very pure green and with Crystal violet or Rhodamine, films may be stained which pass the blue spectral region only. Patent blue is not easily soluble in water, and stock solutions of 1 : 250 only can be prepared, but the addition of other dyes, for instance Tartrazine, increases the solubility of the dye.

Crystal violet transmits the entire blue and violet and a great amount of red rays. In high concentration the solution of this dye appears dark red. This dye is

used to isolate the extreme spectral red or blue and violet. It is used a great deal for the preparation of the blue filter on account of high transparency and good definition of the blue spectral region, but in this respect Rhodamine is still more suitable.

Crystal violet is otherwise a very unsatisfactory dye, forming precipitates when mixed with Patent blue and many other dyes, and is better avoided in trichromatic filter making. Enabling us to isolate the extreme red, the dye is valuable for other purposes. Being somewhat fugitive it is necessary to add a copper salt.

Crystal violet	1 gr.
Copper sulphate	5 gr.
Water	100 cc.
Acetic acid	10 drops.

Green Dyes.—The dyes transmit rays of the green spectral section with transparency maxima either near E *b* or nearer D or F, giving such dyes pure green, yellowish or blue-green hues.

These dyes very often transmit the extreme spectral red, but such rays are of a very low luminosity and do not affect the colour of the dye. Only the blackish green Alizarine dyes or the Naphthol dyes completely absorb the extreme red.

The green dyes offer no advantages against Patent blue and Tartrazine mixtures for green filters, except where complete absorption of the extreme red is required, as, for instance, for certain dark-room safe lights.

Naphthol green is a yellow-green dye containing iron, completely absorbing red, passing ultra-violet. Films stained with Naphthol green are permanent.

THE TECHNIQUE OF FILTER MAKING.

We differentiate between dry and liquid filters. Liquid filters are not very convenient, but they are uniformly coloured filters such as can only be prepared by experts with gelatine or collodion films.

A variety of the liquid filters is a coloured jelly contained in a glass tank and not requiring the care of the liquid filter, which is easily spilled.

Only gelatine may be considered suitable for the preparation of dry filters, because it is extremely difficult to obtain an evenly coloured surface with coloured collodion or varnishes.

There are two types of dry filters. Gelatine films stained and sealed with Canada balsam between two glasses or such films stripped and used as flexible films. The latter are not to be recommended as they are too delicate to handle, and too easily influenced by the atmosphere. As a carrier for such coloured gelatine optically-worked glass of 1·5 mm. thickness is used. The plates are coated with a given quantity of coloured gelatine and dried quickly.

Care must be taken in the selection of the gelatine, which in many cases contains traces of sulphites. The coating has to be done on a perfectly horizontal surface in a room absolutely free from dust. About 7 cc. of a 6 per cent. gelatine solution are employed to coat 1 $cm.^2$ and the solution should be of a temperature of 40-45°C. The temperature of the room should be 15-20°C. After drying, the filter is sealed with Canada balsam.

To obtain coloured films, we coat thick and perfectly clean patent plate glass with 5 per cent. collodion, containing 1-2 per cent. castor oil. After drying, the coloured gelatine is poured on this filter, dried, cut with a knife and stripped.

It is not advisable to add glycerine to the gelatine to make the films more pliable because the permanency of the colour to light is affected. We can also fix ordinary dry plates, washing well and bathing in dye solutions, thus preparing filters useful as safe lights.

No instructions can be given to obtain filters with definite absorptions, which work requires careful spectroscopic measurement.

FILTERS FOR THREE-COLOUR PRINTING.

To obtain perfect decomposition of the colours of an original into three elements, we require filters which transmit rays of one spectral section only, absorbing the other two. Such "normal" filters are always used when theoretical reproduction colours are employed, which is the case in the additive processes of three-colour projection. For three-colour printing, however, where incorrect inks are used, the filters are modified to reduce the amount of retouching otherwise requisite.

Such filters are called "subtractive" filters in contradistinction to the above-mentioned "additive" filters.

A. NORMAL FILTERS (ADDITIVE).

The spectrum has to be divided by these filters near wave lengths $\lambda = 580\ \mu\mu$ and $\lambda = 495\ \mu\mu$. Red and violet rays beyond the lines C and G have to be eliminated, because they are of no influence upon body colours.

The action of rays beyond C may be avoided by using plates not sensitive for such spectral rays, and the ultra-violet can be easily cut out by a suitable filter or both may be considered negligible (*vide* page 79).

Rose bengal gelatine films, 1·5, are most suitable as red filters, because their transmissions are better defined

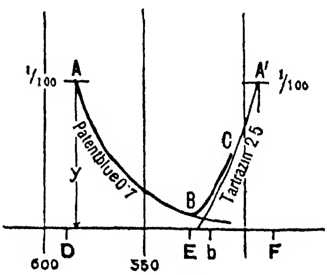


Fig. 34.

than those of most red filters. A yellow film has to be added to exclude the blue rays, Tartrazine films of density 2 being suitable.

The amount of Tartrazine may be increased without altering the transmission of this filter. The green filter has to transmit rays of wave length $\lambda = 580\ \mu\mu$ to $\lambda = 495\mu\mu$. Every other part of the spectrum must be absorbed, a condition fulfilled by filters of a transparency of $\frac{1}{100}$.

If we assume y in Fig. 34 to represent such a film we must construct a filter whose absorption curve passes through the points A and A′. If we examine the absorption of green dyes we find that none correspond to such conditions except mixtures of blue or green with yellow dyes. The curve of the first has to pass through point A, and must terminate abruptly. This requirement is met by Patent blue 0·7.

The most suitable yellow dye is Tartrazine 2·5, which, combined with the blue dye, gives a green with filter curve A B C.

Filter yellow would have to be used in very high concentration.

For the blue filter which is to transmit the blue spectral region, rays of wave length beyond 495 $\mu\mu$, we can stain films with Crystal violet 1·0. If we wish to absorb the

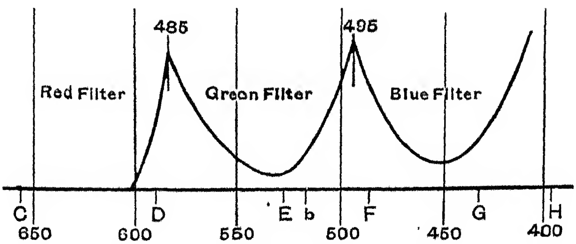


Fig. 35.

ultra-violet, which is not absolutely necessary, we combine our filter with Aesculine 16, or Patent blue 1·6. The latter will also completely absorb the extreme red of the spectrum.

A perfect and very transparent blue filter, passing rays from F to G, may be made with a Rhodamine gelatine film 3·0 combined with a Patent blue 1·0. The above

described normal filters have following construction :—

Red filter : Rose bengal 1·5+Tartrazine 2·0.
Green filter : Patent blue 0·7+Tartrazine 2·5.
Blue filter : Acid Rhodamine 3·0+Patent blue 1·0.

Fig. 35 shows the absorption spectra of such filters, which may be prepared as follows :—

RED FILTER :	Rose bengal	1·5 gr.
	Tartrazine	2·0 ,,
	Water	200·0 cc.
GREEN FILTER :	Patent blue	0·7 gr.
	Tartrazine	2·5 ,,
	Water	200·0 cc.
BLUE FILTER :	Acid Rhodamine	3 gr.
	Patent blue	1 ,,
	Water	200 cc.

Mix 20 cc. of dye solution with 50 cc. of gelatine solution 8 : 100 and apply 7 cc. of such coloured gelatine per 1 cm.[2] of filter glass.

The filters have to be dried quickly and sealed with Canada balsam to another filter glass. For tanks the following solutions are to be prepared :—

A.	Rose bengal	1 . 100
B.	Tartrazine	1 : 100
C.	Patent blue	1 : 500
D.	Acid Rhodamine	1 : 500

For tanks of 5 mm. thickness take :

Red Filter : 30 cc. A+8 cc. B+62 cc. water.
Green ,, 20 cc. B+5 cc. C+75 cc. water.
Blue ,, 10 cc. C+20 cc. D+70 cc. water.

For 10 mm. tanks dilute with equal quantities of water.

EXAMINATION OF FILTER BY USING THE COLOUR CHART.

To test filters in addition to spectroscopic tests, the colour chart on Supplement I. is used, and will greatly assist us in ascertaining the qualities of the filters. Such examination is in certain respects preferable to spectroscopic and spectrographic tests.

The chart contains three components of white light : Vermilion, yellow-green and ultramarine, colours which are equidistant in the colour circle and which give a neutral grey when combined by means of a colour top. The yellow also gives when mixed with equal parts of ultramarine, a neutral grey. To obtain equal purity, the pure colours yellow and red receive an addition of black.

None of the colours can be reproduced lighter than the surrounding grey, whatever plate or filter is employed.

The red, green and blue correspond, therefore, as regards colour tone to the three filters, and we can easily determine the correct reproductions of the coloured squares.

Using the red filters, only the red component of white light rays reflected from vermilion, will be photographically active, and the negative must show equal density in the red field to that of the surrounding grey ; the other, green and blue field, to be transparent in the negative.

The green filter will only record rays reflected from the green and the blue filter from the blue square. Prints made from such negatives should correspond with Supplement IV. If projected and backed with their respective coloured glasses, a reproduction of the original chart in its natural colours will result. The difficulties encountered thereby are discussed on page 66.

Due to imperfect covering power of the pigments the plate will probably show a slight deposit in the squares which are to be rendered transparent. Strictly speaking, the above filters are only suitable for isochromatic plates, but experience shows that the colour analysis is not absolutely dependent upon the spectroscopic sensitiveness of the plate, as is often assumed.

We obtain, for instance, similar results, whether Pinachrome, Orthochrome, Pinaverdol, Isocol or Homocol are used for sensitizing, and only in the case of Pinacyanol *versus* Dicyanin are considerable differences noticeable. This fact becomes a matter of course if we assume the spectrum to be composed of three evenly coloured spectral sections, because in this case it would be immaterial in which part of the section the maximum of sensitiveness of a dye lies.

Different illumination would have no influence upon the colour records, and experience shows equality of result, whether day or electric arc light is used. Only the length of exposure is influenced thereby.

B. MODIFIED FILTERS (SUBTRACTIVE).

Modified filters suitable for three-colour work with theoretically incorrect inks, have to be constructed by empirical means, by using the colour chart as a test object only.

If we consider, however, that the composition of the colours of the colour chart is in accordance with the following equation:

Vermilion = equal parts of magenta + yellow.
Ultramarine ,, ,, blue green + magenta.
Yellow green ,, ,, yellow + blue-green.

the three negatives will have to show different rendering of colour.

In the red negative the blue field will have to be less intense in colour than the red, in the blue negative the green less intense than the blue and in the yellow the red square to be lighter than the green.

To obtain such results we use a more bluish-green filter and a more yellowish-red filter. To meet the requirements of the yellow negative, however, is not possible. There is very little margin in such adjustments and they have to be done with very great care or the balance of the colour system will be completely upset.

If we make our green filter, for instance, too bluish we get an excellent rendering of the green square, but we also notice that the yellow square shows lack of density.

The same holds good when we over-correct the red filter. The red patch loses density. Dianil red, 0·4, is more suitable for such filters than Rose bengal.

For the green filter Patent blue and Tartrazine are used, the latter slightly reduced to shift the transmission band into the blue-green.

Orange filter	Dianil red	0·4 gr.	20 cc. of dye solution are mixed with 50 cc. of gelatine solution, 8 : 100. 7 cc. of this solution per 1 cm² of filter surface.
	Filter yellow	2 gr.	
	Water	200 cc.	
Blue-green filter.	Patent blue	0·7 gr.	
	Tartrazine	0·7 gr.	
	Water	200 cc	

For tanks the following are employed.

Red filter: Dianil red 0·5 + Filter yellow 2·0.
Green filter: Patent blue 0·5 + Tartrazine 1·6.

We deduct the following quantities for 5 mm. tanks:

Orange filter: 5 cc. Dianil Filter yellow (page 104) + 95 cc. water.
Blue-green filter: 7 cc. Patent blue sol. C. (page 102) + 2 cc. Tartrazine solution B + 91 cc. water.

Fig. 36 shows the absorption curves of the modified, or so-called substractive, filters, and Supplement IV. shows reproductions of the colour chart made with such filters.

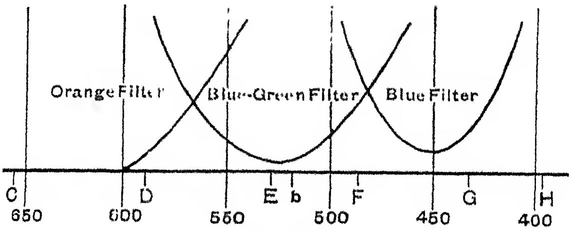


Fig. 36.

Complementary Filters.

We have now to discuss the complementary filter required in four-colour work, which is to adjust the conditions of sensitiveness of the plate so as to render all pure body colours equally light. Such a filter is of a colour complementary to the colour of the photographically active light. Although we are not able to fulfil the conditions of four-colour printing entirely (*vide* page 86) we obtain with complementary filters and isochromatic plates results which are sufficiently correct for practical requirements. The construction of a complementary filter for four-colour work is somewhat difficult, because the filter has to be carefully adjusted to suit the colour sensitiveness of the photographic plate, which not only depends upon the sensitizer, but also upon the method of sensitizing. We cannot maintain that a filter suitable for a Pinachrome plate is suitable for any plate sensitized with Pinachrome; and, again, if adjusted for electric arc light, this filter will be useless for daylight exposures.

To give instructions for the making of such filters is, therefore, impossible. Colour chart Supplement I. will serve again in this case. The three colours, red, green and blue, have to be rendered equally light, but yellow has to be twice as light, because it reflects the entire red and green. Supplement IV. shows the reproduction.

Collodion emulsions are made isochromatic by addition of Pinacyanol+Pinachrome, and require no complementary filter at all. Gelatine plates always require a compensation filter, and Pinachrome is the most suitable sensitizer for such plates. A suitable filter is made by mixing

6 cc. of Filter yellow solution ...... 1 : 100 with
64 cc. of gelatine solution .... 1 : 15

Glass plates are coated with 7 ccm. of such coloured gelatine solution per 1 $cm.^2$

C. THE PRACTICE OF THREE-COLOUR PRINTING.

1. The Making of the Photographic Negative.

Any camera, which is sufficiently rigid in build to permit of changing the plate without shifting, is suitable for three-colour photography. A very minute shifting of the camera alters the dimensions of the negatives, and register of the printing plates would be impossible.

The Filter.—The filters are used in front of or behind the lens, or immediately in front of the plate. To ensure perfectly sharp images optically worked glass is requisite for filters attached to the lens. Short-focus lenses require only carefully selected plate glass, but long-focus lenses give unsharp images if any glass except optically-worked glass with parallel surfaces is used for a filter.

For small size plates (such as half-plates) the filters are best used in front of the plate, as ordinary plate glass is quite suitable for filters in this position ; for larger sizes the filters are used near the lens, and have to be optically perfect.

Tanks made by the firm of Carl Zeiss, of Jena (Fig. 37), consisting of two optically-worked glasses enclosing a glass ring, are recommended for liquid filters.*

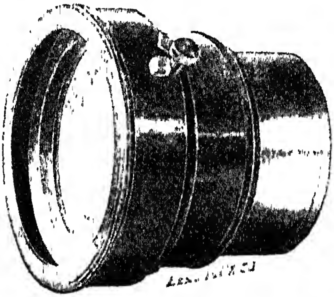


Fig. 37.

The thickness of such tanks inside is always 5 mm. It is, however, necessary to use three such tanks for the three filter solutions, and great care must be taken to select three of exactly the same dimensions, as otherwise differences in the size of the image will result.

The Camera.—To enable us to change plates and filters rapidly, as is necessary in the case of trichromatic landscape photography or portraiture, special dark slides carrying the three plates with the filters in front have been made. Dr. A. Miethe has constructed an arrangement of dark slide and filter carrier in a holder which permits of a rapid succession of the exposures by making the plate holder slide into three positions. R. Lechner introduced a system of prisms with dark slide and filters which are turned 120° for each exposure.

All such arrangements are only of use if still objects are photographed, and the slight movement of the foliage in a landscape is sufficient to spoil the exposures.

Only a camera permitting of simultaneous exposure is of use where moving objects are to be taken, and for

* The square tanks with permanently sealed sides of optical glass, supplied by A. W. Penrose & Co., Ltd., are very convenient to handle, and are much used by English workers.—TRANS.

more or less distant landscape a three-lens camera is probably most suitable. To avoid, however, stereoscopic differences only very small plates can be used.

Abney suggested a very ingenious construction of a three-colour camera which may be described here. The objective is formed by a lens O_1 O O_1 which consists of three different lenses, which, however, require the additional lenses L_1 L L_1 to form complete photographic objectives. The rays of light through O, pass through L, and form an image in P P. Behind the lenses O_1 O_1 very small mirrors S S reflect the rays through lenses L_1 L_1 on to the mirrors S S, which further project the rays upon the photographic plate P P.

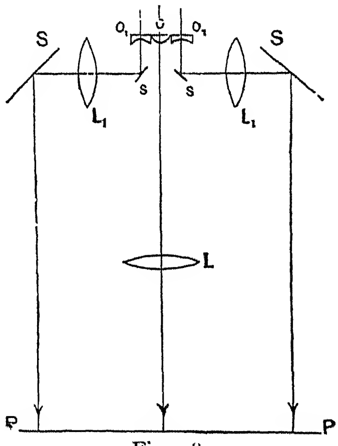


Fig. 38.

We obtain three images of exactly same size and sharpness upon plate P P. Such a camera is very superior to any other construction because it is free from stereoscopic effects and the three images are on one plate.*

Another way of exposing three plates simultaneously

* The Butler One-exposure Three-Colour Camera, with three separate plates, is a type which has proved satisfactory for outdoor photography, and a camera used by the Polychromide Company, of London, has been very successful for portrait photography in colours.—TRANS.

has been made use of by Dr. Smith in his "Filmpack," and has been revived recently by Ives.

Several light-sensitive films are superimposed -one blue-sensitive covered with a yellow filter film, one green-sensitive and one red-sensitive with a red filter film.

The films are separated before development and developed in the usual way.

The Lens. Although not necessary to use large aperture lenses, because our plates are sufficiently rapid, it is necessary that the lens should be colour corrected, so as to give three same-sized images when the three filters are used.

Ordinary lenses show considerable difference between the optical and chemical focus, or between the focus of the blue rays and that of the yellow and red rays.

As the blue rays are generally the picture-forming rays this difference need not be considered in ordinary photography, but in three-colour photography the red rays play a very important part in the picture production. This focus difference amounts in the case of a single lens to 1/50*f*. Corrected lenses show considerably less difference but this is always dependent upon focal length, and is very disturbing in very long-focus lenses.

Special lenses have been constructed by several of the larger optical firms, known by the names of Apochromats, Apochromat, Collinear, etc. (C. Zeiss, Jena, and Voigtlander & Son, Brunswick), and giving same-sized, equally sharp trichromatic images.

Comparative experiments with an Achromat-anastigmat, $1/8f=440$ and an Apochromat-Tessar $1/10f=450$, in the studios of Carl Zeiss, demonstrated the superiority of such lenses.

Focussing the image up to 60cm., corresponding to same-size image, the first-named lens gave a difference of ½ mm. between red and blue, but the second gave absolutely sharp images of almost identical size.

THE PHOTOGRAPHIC PROCESS.

The wet collodion process does not offer a satisfactory colour sensitive plate, and we are compelled to fall back upon one or other of the two emulsion methods.

Whether we decide to use collodion emulsion or gelatine dry plates will depend entirely upon working conditions. Working methods, especially when large sizes are concerned, are considerably simpler and more convenient when collodion emulsion is used. Plates of any size can be coated at a moment's notice and the developing, fixing, washing, etc., is possible without the use of dishes, and is thereby done much more quickly.

Moreover, the colour sensitiveness of collodion emulsion is so high that in many cases filters may be dispensed with, and screen and colour negative may be produced in one operation.

This possibility is of the greatest importance to the practical man, because gelatine plates are not very suitable for screen-negative making, and more or less necessitate employing the indirect process.

Several firms are manufacturing excellent collodion emulsions, and these are supplied in two different kinds.

One is suitable for continuous tone and the other for screen-negative making. They are very different as regards gradation, working either very soft or very contrasty.

Special sensitizers are also on the market, these being Eosine-silver compounds, or containing either Ethyl-violet or the Cyanines as active dyes. The sensitizers can be mixed with the emulsions or they may be diluted with alcohol and poured over the previously-coated emulsion plate. The developer contains hydroquinone and potassium carbonate for screen negatives or glycin for continuous tone work. The reduction, intensification, etc., of such plates is similar to that of the ordinary wet collodion.

In the place of the commercial sensitizers the following

sensitizers may be used, and these act with such intensity upon collodion emulsion that filters are not absolutely necessary.

(*a*) Blue printing negative: Pinacyanol, water bath, green dark-room light.

(*b*) Red printing negative: Uranin or Mono-bromo-fluorescin of sodium silver compound, red dark-room light.

(*c*) Yellow printing negative: Ordinary emulsion, red dark-room light.

(*d*) Black printing negative; Pinachrome + Pinacyanol, water bath, very dark-green dark-room light.

Despite all its advantages collodion emulsion is not always suitable, because great cleanliness and care are required. The working rooms must not be too hot, and other processes cannot be worked in conjunction with emulsion.

In particular the amateur will prefer to make his trichromatic negatives with ready-made gelatine plates, because his dark slides are not suitable for collodion emulsion plates, which must be exposed in a moist state.

Bathed Pinachrome plates will be most suitable for his requirements. The three plates must be developed simultaneously, and treated otherwise exactly alike.

Dr. A. Miethe always laid great stress upon this condition—the necessity of a perfectly automatic procedure.

For the decomposition of colour in methods of process reproduction collodion emulsion is most suitable, offering quick and very convenient working methods and ensuring good results.

CONTROL OF THE NEGATIVES.

We do not wish to assert that the accurate working methods conditioned by the dry plate are not in place in the case of trichromatic work for process reproduction, but if errors occur they are more easily corrected by retouching or fine etching, which is always requisite.

To judge the negatives better it is advisable to photograph a grey scale with the original, because the grey of the scale reproduction does not depend upon colour sensitiveness of the plate or upon the filter, but is conditioned by the photographic gradation of the plate itself.

Platinotype copies are very suitable for grey scales which are to show four or five different gradations The three negatives are to render the grey scale exactly alike.

If there are large amounts of one of the colour components in the original, as, for instance, most noticeable in the yellow printing negative, the negative will often appear under-exposed. This should not lead to error, because the negative is correctly exposed if the grey scale is rendered equal to the other two reproductions of it. In many cases the three negatives differ very little from each other and give the impression that the colours are not sufficiently separated, yet they are correct.

Even a very experienced chromo-litho artist could not judge whether negative or print is correct as regards colour decomposition, because mixtures of three so widely different colours are novelties to him.

It appears almost incredible that black, grey and all shades of browns may be derived from mixtures of blue and red, that the colour of ultramarine is composed of magenta red and greenish blue, and that vermilion owes its origin to magenta red+sulphur yellow.

We can only make sure of correct filters and colour-sensitive plates, and use as a check a colour scale (Supplement I.) which assures us of a perfect colour selection.

FILTER RATIO.

The ratio of exposures is of greatest importance and to control such we use a grey scale during our exposure. In the case of landscape or portrait trichromatic photography such a scale cannot be used and the ratio of filters has to be determined before exposure.

We photograph for this purpose a plaster cast using the three filters, developing in the same dish and repeating exposures until uniformity of the three negatives is achieved. The necessary exposures determine the ratio of the filters. Such a ratio holds good for a certain set of filters and a certain plate, but depends also upon the illumination. Even daylight shows considerable variations influencing the filter ratio.

Dr. J. M. Eder found exposure ratio during a sunny day to be 1 : 2½ : 3, and on a foggy day 1 : 1½ : 3, and Dr. E. Stenger came to the conclusion that decreased intensity of light conditions caused an increase of exposure for red and green.

Dr. A. Miethe recommends ascertaining filter ratios on a sunless day, when the light is very white, and to retain such a ratio for all outdoor photography.

Although not strictly correct, this advice is sound enough, because colour photography is not usually practised on foggy and rainy days.

Such inconsistency of light conditions is, of course, very disturbing in reproduction studios where daylight is used.

KLEIN'S "RATIOMETER."

H. O. Klein has constructed a very ingenious little instrument which enables us to measure filter ratios at any time with certainty ; this he calls "The Ratiometer."

This instrument consists of a little box, which takes the photographic plates with the trichromatic filters covering the same.

Above the filters is a roller shutter with an adjustable opening permitting of five different exposures with each filter. To reduce the intensity of light a glass scale of grey

neutral colour covers the slit.* The "Ratiometer" is held against a white surface reflecting the light which is used for the camera exposures, the light thus passing through the colour filters and exposing the plates by means of the moving slit.

The plates are then developed in the same dish and we obtain five densities corresponding to five exposures with each filter. As the exposures are known, it is not difficult to select three equal densities and to establish the filter ratio.

If, for instance, strips of equal densities correspond

Under	blue filter to exposure of	..	5	seconds.
"	green " "	......	15	"
"	red " "	......	15	"

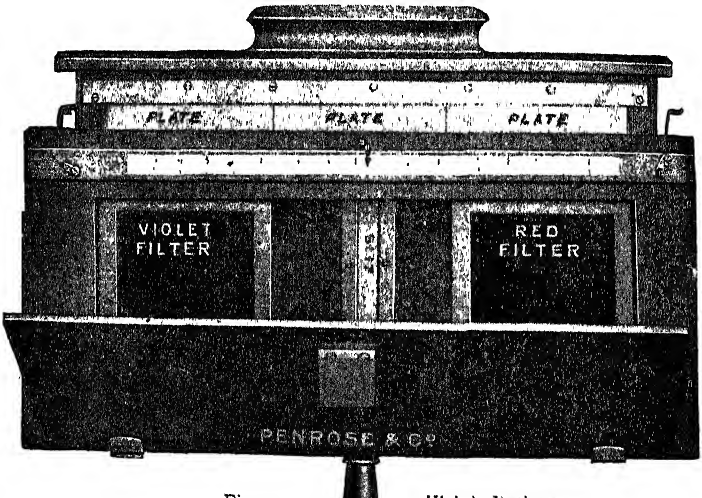


Fig. 39. Klein's Ratiometer.

* The translator is indebted to Dr. Kenneth Mees for the suggestion to subdue the intensity of the light transmitted through the slot by means of a grey glass, when using the "Ratiometer" against very brightly illuminated surfaces, advice which has been made use of in the construction of the new "Ratiometer." Dr. Miethe's observations, referring to the absorptive properties of glass and cement, and the consequent alteration of filter ratio, led to the suggestion that the "Ratiometer" should be exposed to the light reflected from a white sheet of paper after its passage through the lens in the camera itself, the lens aperture being in all cases sufficiently large to cover the entire slot of the "Ratiometer."—TRANS.

the ratio established for such plates and filters will be, according to the Ratiometer, 5 : 15 : 15 or 1 : 3 : 3, which tells us that we are to expose three times as long with the red and green as with the blue filters.

Under normal conditions—white illumination, normal filters, Pinachrome bathed plates—the exposure ratio as given by Klein's Ratiometer is for blue, green and red 1 : 3 : 2, and with subtractive filters as 1 : 1½ : 1.

The filter ratio may be influenced by the lens. Dr. A. Miethe observed considerable differences when exposing with various lenses, finding that thick lenses with many sealing surfaces absorb more blue than thin lenses.

The ratio of an anastigmat with two treble-sealed lenses is as 1 : 7 : 8·5, against that of a lens with three single separated lenses of ratio 1 : 9 : 12·5.

Both lenses are, of course, suitable for colour work, but some care will have to be taken when a change of lens is made which is likely to alter the filter ratio.

THE ILLUMINATION OF THE ORIGINAL.

The use of daylight is, of course, preferable to any other light, but for many reasons the use of electric arc light is almost enforced in reproduction studios.

We have two different types of arc lamps at our disposal, the "open" and the "enclosed" type. Ordinary carbons or those saturated with metallic salts may be used, the latter kind influencing the colour of the light and reducing exposures. For ordinary black and white photography the "enclosed" lamps are in general use, because they require very little attention and their light is very rich in violet and blue rays, which are "photographically" very active. Such rays, however, are not required in three-colour photography except for the production of the yellow printing plate.

Newton and Bull experimented with various arc

lamps, using a grey scale and determining the exposures needed to give equal reproductions.

	Exposures in Minutes.			
	Blue.	Green.	Red.	Total.
Ordinary open arc	15	15	25	55
Enclosed arc	10	30	60	100
Enclosed arc, using "white" carbons	15	20	30	65

Such observations teach us that the "open" arc is very superior to the "enclosed" arc for trichromatic reproductions. Small originals require two lamps, one on either side, but originals of about 1 m. require two pairs of "open" arcs of 20 amps. each.*

It is very difficult to evenly illuminate large originals, because to obtain even illumination the lamps have to be at a considerable distance from the original, which in the case of old oil paintings, especially when direct screen colour negatives are made, gives quite insufficient illumination.

Although electric arc light is reddish yellow in hue if compared with sunlight, the resulting differences in the colour are so very minute that a correction of filter for daylight and electric arc exposures is hardly requisite. W. Gamble made the suggestion to change the colour of the illuminating light instead of changing the filter. He proposes green light for the red printer, red for the blue and blue for the yellow.

Experiments have shown that the time of exposure for the blue plate can be reduced to half by using red flame carbons in "enclosed" arc lamps, but the green filter cannot be dispensed with, because there is no green burning carbon in existence.

The firm of Penrose & Co. have constructed an arc lamp which carries three pairs of carbons and which can be switched on alternately.

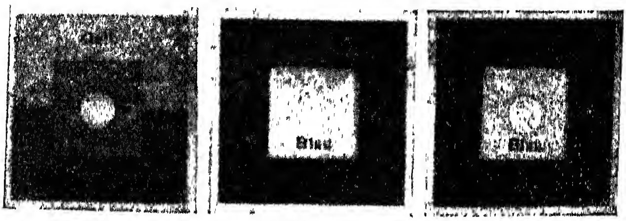
* Penrose & Co. have recently introduced "open" arc lamps, which burn with a long flaring arc, similar to "enclosed" arcs, and using chemically prepared carbons giving a very pure white light. These lamps are very suitable for colour work and enable very short exposures to be obtained.—TRANS.

COLOUR SELECTION FROM AUTOCHROMES.

The difficulties encountered in such colour selection are not, as usually stated, due to the impurity of the colours owing to admixture with black, but due to admixture with white.

The screen elements are only insufficiently covered by the silver deposit of the Autochrome plate and every part of the picture permits of the passage of red, greed and blue light in varying degrees of intensity. Parallax phenomena appear also, and cause a further addition of white.

If we print, for instance, the Autochrome image on an ordinary photographic (blue sensitive) plate we obtain the result A, Fig. 40.



*A B C

Fig. 40.

We should have expected a yellow colour selection as C shows, but rays of light passing at acute angles through the blue filter elements are acting partly through the other two colours. To consider A to represent a yellow negative is by no means permissible, nor is any contact copy made in the printing frame on colour sensitive plates.

Such parallax disturbances are avoided if we make our selections in the transparency camera. We obtain then the picture *c*, which does not quite fulfil the conditions of a yellow printer, which C represents. The other two selections are better, but not perfect, and a good deal of retouching is always required.

* "Gelb" and "Blau" on the diagrams are the German words for yellow and blue.—TRANS.

It is advisable to direct the camera, when making the selections, towards the sky, because if electric light is used it will be necessary to diffuse the light with four to six matt glasses, which absorb a great deal of light, or to use a condenser arrangement similar to that of the usual enlarging apparatus.

The usual trichromatic filters are always used, even when employing collodion emulsion, which otherwise can be worked without colour filters.

If electric light is used care must be taken to protect the Autochrome from too intense heat, which is likely to split the film. It is better not to varnish the transparency, but to apply glycerine.

DARK-ROOM ILLUMINATION.

The introduction of red-sensitive plates made the addition of a green dark-room light a necessity. This light has to be used as subdued as possible, and wherever permissible dark red light will be preferred on account of its high illuminating power.

Gelatine or collodion emulsion plates sensitized with Eosine Sensitizers are worked in red light, but if Ethyl-violet, Dicyanin or Pinacyanol is used, medium green light, and for Pinachrome and Pinaverdol very dark-green light, is employed.

Such safe lights are products of commerce and can also be prepared by coating glass plates with specially prepared coloured collodion or gelatine.

2. The Production and Superposition of the Component Pictures.

A. Three-colour Printing.

Three-colour printing, a process of great importance in present-day illustration, may be practised by using three blocks, or by adding a fourth, a grey print, to the yellow red and blue impression, which variation is called "Four-colour printing."

It is necessary to determine whether the blocks are to be printed in "theoretical" or "practical" inks, because the choice of filter will be considerably affected thereby. Normal (additive) filters are used in the first, and modified (subtractive) filters in the second case.

Printing Inks.—Theoretically correct printing inks are well defined and can easily be checked as regards purity and hue by using the gelatine films, page 59, as comparison objects. Wratten & Wainwright have introduced a little instrument called an "Ink tester," which consists of six coloured films representing the fundamental colours red, green and blue, and the secondary system corresponding to Patent blue, Erythrosine and Normal yellow.

The inks which are to be tested are printed as overlapping circles similar to Supplement I., and examined by viewing same through the coloured films. The primary red filter should show the blue printing ink as deep black, magenta very light, and yellow invisible.

If the blue appears brown, we obtain by mixing the three colours a reddish brown in the place of a pure black.

The green filter should show magenta absolutely black, yellow invisible, and blue-green very light. An ideal blue-green should also be invisible, but we possess no blue-green body fulfilling such requirement (page 58).

Viewed through the blue filter the yellow printing ink must appear very dark, but magenta and blue-green very light. Strictly speaking, the last two colours should be invisible, but no red ink meets such a condition.

The secondary colour filters serve for the examination of the colours produced by the overlapping of the fundamental triads, and are vermilion, yellow-green and pure blue. The secondary blue-green filter must show vermilion black, blue-green very light, and magenta of a blue colour.

The secondary red filter must give blue-green as blue, magenta invisible and yellow as vermilion.

The secondary yellow filter should give blue green as a brilliant yellow-green, magenta as vermilion and yellow invisible.

Similar examination of printing inks may also be made by using the colour top (page 45). Wratten & Wainwright, with the collaboration of Dr. K. MEES, have endeavoured to select standard inks, and the firm of Mander Bros. have been induced to bring the following inks on the market—Red 0367, Blue 0368, Yellow 0366. The red is correct in hue, but is somewhat fugitive, and may be likened to the Nacht Rosa of Kast & Ehinger.

The red 5971 of the last-named firm is fairly permanent although in dense layers it is not bluish enough in hue.

Much more unsatisfactory are the blue colours which, apart from considerations of permanency, are never sufficiently greenish in hue.

Blue 0368 of Mander Bros., and Blue 5514 of Kast and Ehinger may be considered permanent printing inks. The peacock blue of the last-named firm is very pure, though not sufficiently greenish in hue, and is also very fugitive.

The yellow inks present no difficulty as regards permanency and correct colour hue. Yellow 0366 of Mander Bros., Yellow 2997, and Chrome yellow extra 1½ of Kast & Ehinger are quite satisfactory. The chrome yellow, however, like every chrome yellow, darkens on exposure to sunlight.

Theoretical printing inks, however, are very little used and printing inks cannot be defined which meet all the different working methods of the practical process worker. It is simply a matter for the photographer and fine etcher to work hand in hand on the basis given by a certain ink set, and this always necessitates a great deal of retouching.

Dr. J. HUSNIK refers to such "practical" inks as follows: "The yellow should be very pure, never of a reddish, but rather of a greenish hue. Crimson lakes are

most suitable for the red ink, and shades should be selected which show a fiery red, and are devoid of any bluish hue. The blue is to be of a greenish tint in thin layers, but pure blue otherwise.

Such colours are far removed from those considered theoretically correct, yet the three-colour prints of the firm of Husnik enjoy the best possible reputation. Another firm using altogether different inks may, however, achieve equally good results.

To meet so many different requirements, a great variety of three-colour inks have been introduced by ink makers. The red inks of Kast & Ehinger show, for instance, a red-blue relation of 1 : 2 and 1 : 4, and that of the blue printing inks varies between a green-blue relation of from 1 : 4 to 1 : 6. We find in this list of trichromatic inks a pure blue 3782 and a very blackish blue 1703.

As yellow printing ink the greenish yellow 4945, or a reddish yellow 1699, may be selected. Not only is it possible to select a colour system to suit certain working conditions, but also to select printing inks to suit the colour peculiarities of certain originals.

If greys and blacks predominate it is advisable to choose two colours containing black, because the more impure the colours the easier it will be to obtain neutral greys.

This great latitude, permissible in three-colour printing from half-tone blocks, where the more delicate colour shades are produced by colour components placed more or less side by side—thereby ensuring comparatively pure colour mixtures—is not possible in other printing methods like Collotype or Photogravure.

Such printing methods require printing inks much more in accordance with the theoretical standards.

DEFICIENCIES OF THREE-COLOUR PRINTING.

Granted the possibility of getting perfect colour negatives, and the use of theoretically correct inks, the

imperfections due to superposition are very considerable and make it impossible to demand absolutely faithful reproduction of the original. As explained on page 49 the last printing colour will always absorb rays of the other two which are superposed on it, and it is necessary to make the first and second impressions much deeper than the mixing laws require. This secures a better reproduction of some colours, but injures the necessary balance of the fundamental colours. This defect is chiefly noticeable in blackish colour shades and greys.

Another disturbance is caused by the imperfections of the letterpress printing, hand presses, for instance, being quite useless for three-colour printing.

Such difficulties are peculiar to three-colour printing, and do not apply to chromo-lithography where from 10 to 30 stones are used to reproduce the colours of an original.

Where we have only three colours to deal with, and one of the components is not sufficiently well pronounced, the whole character of the three-colour print is altered. The colours become incorrect, and we obtain brown or violet in the place of greys. Large surfaces, moreover, appear mottled, due to imperfections of the negative, or of the block, or through insufficient ink.

A grey background or a grey building appears in places pink or greenish, the colours losing harmony, and the general impression being unpleasant.

FOUR-COLOUR PRINTING.

To obtain fac-simile reproduction we are compelled to use the four-colour process, which is based on theoretically correct printing inks.

Slight differences in the three impressions are not followed by such noticeable defects, and it is easier to print uniform editions with four colours.

Moreover, three-colour printing is considerably cheaper, and is quite suitable for every-day illustration, where no high demand for colour accuracy is made.

Another modification of four-colour printing, where two blue impressions are made use of, has been suggested by R. Ross.

He prints the principal blue plate with a reddish blue (1612 Kast & Ehinger) mixed in equal proportions with blue lake, and the additional blue with Peacock blue, or the Permanent blue 5514. The first blue impression assures correct rendering of deep blues and violets, and the second of the pure greens.

Both blue plates are made from the ordinary blue negative, and retouched according to requirements.

THE ORDER OF PRINTING.

The usual order of printing is yellow, red and blue. The blue, being the darkest colour, covers the other two, prevents the formation of reddish brown in place of grey tints, and ensures a deep black.

Yellow cannot be used as the last colour, because, being a light colour, the picture is made flat and appears faded. If the original contains much green it is advisable to print the yellow over the red. The order of printing in four colours is greatly varied; some print the black first, then the yellow, red and blue. The black loses thereby its drastic effect, and acts more like a delicate grey, the adjustment of the other colours being greatly facilitated.

Sometimes yellow, blue, red and black are recommended as the correct order, because blue prints best on a single colour layer, and the red print can be easily adjusted to suit the first two colours.

We can make use of relief, flat or collotype printing for three-colour work. Photogravure, however, cannot be considered, on account of insufficient transparency of the printing inks in use and the costly character of the process. Photogravure, however, may be very useful for the fourth plate in four-colour printing.

BLOCK PRINTING.

The half-tone process has reached a very high state of perfection since good screens, the enamel process, and etching machines, etc., were made available, and this process, formerly only used for cheap illustrations, has become a serious rival of collotype, which it has almost superseded for art reproductions. Half-tone, not being influenced by climatic conditions, and assuring uniform editions, is also more suitable for three-colour printing, because the superposition errors (page 49) are less marked. The printing ink does not come in contact with water, and retains, therefore, full purity. Moreover, the printing paper remains dry, ensuring perfect register.

On the other hand, half-tone is, least of all processes, capable of reproducing the exact tone values of an original. The shadows are either not sufficiently transparent or the lights lack detail; the gradation is limited, and over the whole picture are dots, destroying the colour hue of the lighter tints.

Three-colour half-tone not only requires considerable retouching on negative or transparency, but the result depends more upon the clever work of the fine etcher than upon the perfection of the photographic records.

THE DIRECT AND THE INDIRECT PROCESS.

The older, indirect method of three-colour half-tone printing required the making of a transparency from the original negative by the usual contact printing processes.

Half-tone negatives were made from such diapositives in the camera. To avoid this complicated procedure, direct three-colour half-tone methods were introduced, these being based upon the use of collodion emulsion.

Both processes have advantages and disadvantages, and much depends upon the local working conditions as to whether the one or the other is to be recommended.

Dr. J. Husnik, a well-known practical expert on such matters, writes as follows:

"The greatest advantage of using the direct process lies in the economising of time and material, and the greatest point in its favour is its better rendering of tone gradations. It stands to reason that during the operations of making the diapositive and negative a great deal of the essential uniformity of the three negatives is lost.

"This alone speaks volumes for the direct process, and the first impressions fully justify its praise. Fine etching is considerably reduced and simplified by direct methods, and, moreover, no fine etching can ever recover tone gradations lost by indirect methods.

"Yet the use of collodion emulsion requires extreme care, for it may be found necessary to repeat a negative five or six times on account of spots or other defects. Collodion emulsion appears to be more suitable for the reproduction of light than of dark originals, on account of a tendency to close in the high-lights, which is most noticeable in great reductions."

The above seems to suggest that the use of the direct process for all classes of work is not advisable, yet the direct process serves most excellently in the majority of cases.

Dr. E. ALBERT introduced a very novel method of producing half-tone blocks which has the only disadvantage of requiring an elaborate installation, which smaller firms do not possess.

Dr. Albert places a continuous tone negative and a half-tone screen upon the sensitized metal in a special rotating printing frame. The screen would under ordinary conditions of lighting project its image sharply upon the metal plate, but on account of the rotation a screen effect is obtained similar to that in the camera during a half-tone exposure.

We only require continuous tone negatives for this process, and these are much easier and quicker to produce than screen negatives. Retouching of the continuous

tone negative is also possible, the sharpness of reproduction is greater, and a better tone gradation is also assured.

The advantages of the Albert process are very considerable, but it is desirable that this process should be simplified, when it may become generally useful.

THE SCREEN ANGLES.

If two screens are printed over each other at a very narrow angle a pattern or moiré is obtained. To avoid this the screen pictures are made to cross at an angle of 30° and special diaphragms are used to obtain chain-like lines, which are easier to etch, because they break up in the high-lights into single dots. Other firms use single-line screens, crossing at an angle of 60°.

Both methods are capable of giving good results, but much depends upon the skill of the operators. Three-colour prints with cross-line screens show a star-shaped or circular pattern, which in no way impairs the beauty and harmony of the pictures.

Circular screens, which can be rotated in the camera, are very convenient. Slit stops are used, and the screen position towards the plate can be regulated by means of special micrometer screws.

Special "three-colour screens," ruled at suitable angles, have been used in connection with the ordinary ruled screen, and the turning of the screens is not then required.

The ruling of the ordinary screen is diagonal, whereas that of the colour screens is 30° and 60°.*

Two negatives are taken with the colour screen, turning the screen 180° for the second.

The third is made with the normal screen, and three negatives with an angular difference of 30° are thus obtained. Such screens, however, are not to be recommended, because they permit of no variation in the turning of the screens.

* A 75° screen works best with the ordinary 45° screen, and can be turned to give 105°.—TRANS.

For four-colour printing cross-line screens may also be used, the relative position being 30° between red, blue and black. The yellow should be placed between the red and blue.

Experiments with grain screens for the yellow plate have not proved successful, because prints made with such screens always appear very rough and are devoid of delicate gradation.

In the case of very small sizes the diapositives are fixed together in a special carrier in the correct positions, and then photographed with the ordinary cross-line screen.

RETOUCHING OF NEGATIVE AND BLOCK.

One of the chief reasons why retouching is required is the incorrect relation between negative and printing ink, due to the imperfection of the latter.

A great deal of retouching can be avoided if we consider the requirements of the blocks when making the half-tone negative.

L. TSCHORNER formulates the following conditions:

"The yellow printing negative should be very soft, giving almost the impression of a tint negative. The red printing negative, however, should be very contrasty. Only the deepest parts of the original should show very small dots. The blue printing negative should show the character of a good normal half-tone negative with plenty of detail. The black printing negative depends upon the character of the original, but should generally be like the red printing negative."

In indirect processes a great deal of retouching can be done on negative and diapositive. This is not possible in direct processes, in which all retouching must be done by means of fine etching on the block itself.

Such fine etching consists in painting certain parts of the block with acid-resist varnish, and re-etching other parts which are required to print lighter.

The graver is also occasionally made use of to cut out certain parts, or the burnisher, which when pressed against the minute dots on the metal broadens these little printing surfaces and makes such parts print darker.

The yellow printing plate requires little retouching, except in red and violet parts, but the red printing plate requires a great deal of work, because this plate should be extremely delicate in green or blue parts of the picture.

The blue printing plate is always the best, but requires to be full of detail, as it is printed in the darkest colour. The fourth printing plate must hardly show any dots in pure colours.

PROOFING.

We understand by proofing the making of the print which is to serve as a sample for the entire edition.

It is necessary to use the same inks, paper, varnishes, etc., as used on the presses which print the edition, and only then can such first proofs be considered a satisfactory basis to work upon.

The intensities of the three prints should be adjusted so as to give grey and black as neutral as possible, and if an "underlay" is not sufficient to get the desired result the blocks will have to be re-etched and proved again.

This procedure must be repeated until a perfect first proof is obtained, and on no account should it be assumed that the careful registration, etc., of the printing presses for the edition may give better results.

SURFACE PRINTING.

The best results are obtained by using half-tone negatives, when printing from stone or metal surfaces, because the methods based upon grained plates for the breaking up of continuous tone negatives are, so far, not satisfactory.

If the half-tone negative is required for printing or transferring on to metal or stone, it must show a very differ-

ent character from that used for the making of process blocks. The high-lights have to be very much closed, and the shadows must show relatively large dots. The negative can either be printed on metal, which is sensitized with asphaltum or with bichromated fish glue, or on to sensitized gelatinized paper, from which it can be transferred.

The transfer process is not satisfactory for half-tone, because even coarse screens give only rough, uneven tones, and the smoothness of the screen image is entirely lost. Infinitely better results are obtainable by the direct methods which give almost perfect printing surfaces, but very little retouching can be done on the printing plates. It is, therefore, necessary to use theoretically correct printing inks, which do not require extensive retouching. Moreover, it is difficult to get pure greys with such inks, and the use of a fourth printing plate is requisite.

For this reason the photo lithographic three-colour process is rarely used, but a change in this respect is possible in the very near future.

The printing from ordinary blocks requires very smooth surfaced papers, which are coated with baryta. Such papers, however, destroy all artistic appearance of a colour print on account of their greasy gloss and chalky touch. The rotary offset machine offers a printing method entirely independent of paper surface and permitting of the most delicate transfer on to a very rough water-colour paper.

There is no doubt that the value of such a printing method is realized, and great efforts will be made to further improve the photo-mechanical methods of printing from continuous tone negatives on to zinc or aluminium, which form the basis of offset printing.

Until then the offset machine should be of great service for ordinary half-tone colour printing. The screen negatives are printed in a pneumatic frame. Theoretical inks are used, and aluminium plates are prefer-

able to zinc plates, because they are not so liable to block up and smudge the half-tones. This process offers so many other advantages that it would be advisable in many cases to make transfers from relief blocks for printing on the offset machine.

Three-colour surface printing deserves fullest attention, because we possess no other process which offers facilities for such rapid and excellent output.

Collotype.

In the former processes a decomposition of the picture into dots or lines is required, but collotype gives perfectly photographic and almost grainless half-tones. This feature of the process should make it especially suitable for tri-chromatic work, but the relatively difficult treatment of the printing plate, and the irregularities in a large number of the prints, greatly limit its possibilities.

Collotype will, therefore, result in a great amount of waste prints, especially as the over lapping defect is more noticeable than in half-tone.

The process is very suitable for small editions, especially where the colours of the original are of a delicate nature. The reversed negatives necessary for collotype can be produced by means of a prism or mirror, or, if collodion emulsion is used, they can be made by exposing through the glass, but this requires specially designed dark slides. Stripping is not recommended on account of unequal stretching of the film.

The three theoretical colours are used, but additional colours are generally added.

Collotypes can be produced in any size, the printing plates can be quickly made, and the process is very suitable for the reproduction of paintings.

D. PHOTOGRAPHIC THREE COLOUR PICTURES.

Three-colour printing is a complicated process and only suitable for large editions. Methods suitable for the amateur have been introduced, but they are all more or less difficult, and require a great deal of time and patience.

The Autochrome plate, giving perfect colour reproduction, is only suitable for lantern projections if powerful electric light is used. Considering the great importance of the projection of educational subjects in schools, colour lantern slides of higher transparency than the Autochromes are badly required.

Three-Colour Transparencies.

The superposition of three transparent coloured images allow every component colour to be fully active, and such methods guarantee a more faithful reproduction of colour than three-colour printing. As the films are stained blue-green and magenta the normal (additive) filters have to be used. To adjust the three films so as to obtain neutral greys is extremely difficult. The slightest excess of one or the other colour is instantly felt, yet slightly incorrect colour rendering is excused by the colour magnificence of the projected transparency. Such transparencies can never rival the Autochrome, but on account of the great amount of light they transmit are of distinct value.

Bichromated gelatine is generally used for the printing of the films, which are stained with aniline dyes.

Dr. Traube's Diachrome process, however, is based on the conversion of silver iodide images into dyestuff pictures.

Coloured Gelatine Pictures.

Celluloid films coated with gelatine are bichromatized, printed through the celluloid and developed in warm water.

To be able to control the development and to prevent too high a relief a bromide of silver gelatine coating is employed. Such films are sensitized in ammonium bichromate solution 1 : 50, dried, and printed in the shade.

The prints are developed in warm water of a moderate temperature to prevent shrinking of the film. After development the films are fixed in hypo, to which a few drops of ferricyanide of potassium solution have been added. A perfectly colourless gelatine image is obtained, and this is washed and stained in the following solutions:

RED:	Water	100 cc.
	Erythrosin sol. 1 : 200	5 cc.
	Alcohol	10 cc.
BLUE:	Water	100 cc.
	Fast green bluish 1 : 200	20 cc.
	Alcohol	10 cc.
	Acetic acid	10 drops.
YELLOW:	Water	100 cc.
	Naphthol yellow sol. 1 : 200 ..	10 cc.
	Alcohol	10 cc.
	Acetic acid	10 drops
	Satur. chrome alum sol.	5 cc.

The films are left in these solutions until perfectly saturated in colour, which often requires several hours.

More concentrated solutions flatten the picture, but act more quickly; very diluted solutions, although requiring more time, give very brilliant pictures, showing much detail in the shadows. If the picture is treated with water or very weak borax solution the highest lights begin to lose colour. Based upon this fact we can alter the character of the pictures and their intensity until the desired result has been obtained.

After these operations are finished, the films are drained and immersed in the following solution:—

Water	1000 cc.
Alcohol........................	100 cc.
Acetic acid	10 cc.

This solution frees the pictures from all dye which is not bound by the gelatine, without reducing the colour of the picture.

Dr. E. Hesekiel modified this process by using a chloride of silver positive, which is immersed in a 1 : 10 solution of ferricyanide until bleached, washed and treated with iron perchloride until the desired blue colour is obtained. This blue picture is immersed in a hypo bath for 1-2 minutes.

PINATYPE.

The "Höchster Dye Works" introduced a three-colour process called "Pinatype." This process requires the production of diapositives from the three-colour negatives, and printing upon bichromated gelatine films on glass supports.

The red and green filter diapositives are printed upon the bichromate film and they are stained blue and red. The yellow picture is then printed upon the red picture and both glass plates are superimposed.

THE "DIACHROME" PROCESS.

This process has been perfected by Dr. Traube, and is based upon the property of iodide of silver to assume the colour of certain aniline dyes.

A diapositive is made upon a chloride of silver plate, which, after development, is treated with a suitable iodine solution to convert the silver image into an iodide of silver picture, which is stained. The gelatine remains unaffected during the process. The iodide of silver image is finally dissolved in hypo to which a small quantity of tannin has been added. The films are finally stripped and superimposed.

THREE-COLOUR PICTURES ON PAPER.

Probably the best results so far have been obtained by using the Pinatype process where the gelatine image is strongly impregnated with a dye, which is transferred upon gelatinized paper. The Pinatype process requires considerable skill, but is capable of giving excellent results.

THE THREE-COLOUR CARBON PROCESS

has been greatly simplified by the New Photographic Co. through the introduction of their Rotary process.

Transparent celluloid films serve as support for coloured films which after Bichromatizing are printed through the celluloid, and developed in warm water. The colour images are finally transferred to gelatinized paper.

CONCLUSION.

It will be gathered from the foregoing description of the various methods of colour photography that the Photochromoscope, as well as the three-colour process, is based upon sound theoretical principles, and is fully justified from a theoretical standpoint.

The difficulties with which the practical man is faced when working the various processes are, however, very different and are the most formidable in the three-colour process when based upon process work.

Theoretical considerations, as well as practical experience in the last-named process, teach us that epoch-making progress is not to be expected in three-colour process work.

We have arrived at the conclusion that it is more or less immaterial whether or not the photographic colour analysis is absolutely correct, that experiments with printing inks of a more theoretically correct nature are without improved results, that the most progress has been made in perfecting printing blocks and printing machines, and that the skill of manual labour, such as fine etching or retouching, is the greatest factor in solving the problem of three-colour process work.

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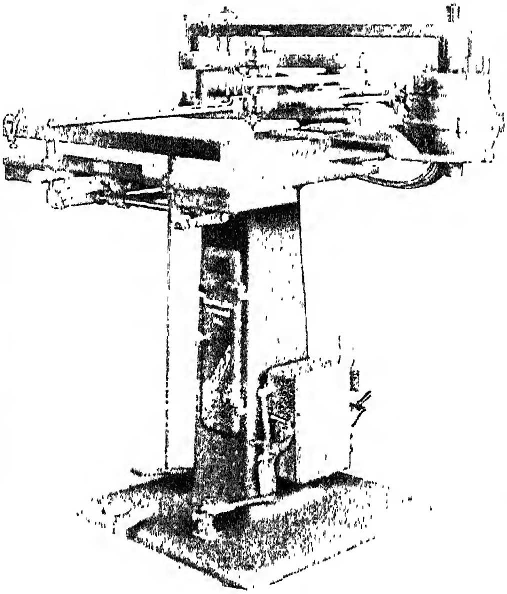
ROUT YOUR COLOUR PLATES

ON A

Royle Router



ROYLE ROUTER.

The Royle Photo Engravers' Machines have an established reputation everywhere for uninterrupted service. The painstaking care with details, the expert workmanship, the better construction throughout, give these machines a steadiness of service both pleasing and profitable to the user

Manufactured by **JOHN ROYLE & SONS,**
Paterson, N.J., U.S.A., Makers of Photo-Engravers' Machinery

Sold by the Sole British Agents: **A. W. PENROSE & CO., LTD.,**
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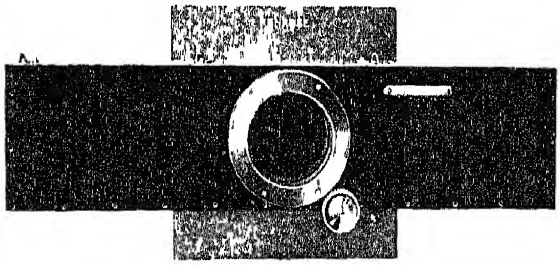
And at Manchester, Birmingham, Paris, Amsterdam, Madrid, Milan, Bombay, Calcutta, Sydney, Toronto, New York, Chicago, Petrograd, etc

Penrose's Triple Colour Filter Holder.

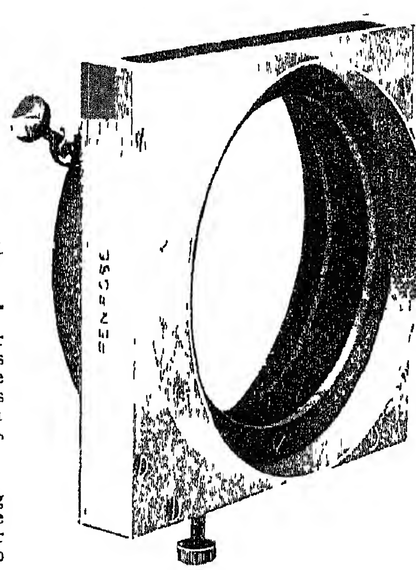
Used by Leading Colour Firms



This useful appliance overcomes many of the troubles incidental to three colour work It ensures good register Being constructed of metal it works with great accuracy and smoothness It is also a great convenience to have three filters in one holder and in line, so that by operating the pinion either colour can be brought into place in quick succession

Penrose's Metal Filter Holder.

for attachment to front of Lens or Prism Box



Some workers prefer the colour filter in front of the lens This holder enables that to be done in a very practical way It is made sufficiently large for liquid colour filters as well as for dry filters

The holder is made of Aluminium with brass clamping ring and brass hood ring Made to take standard sizes of colour filter tanks, but will be made to order in any other size

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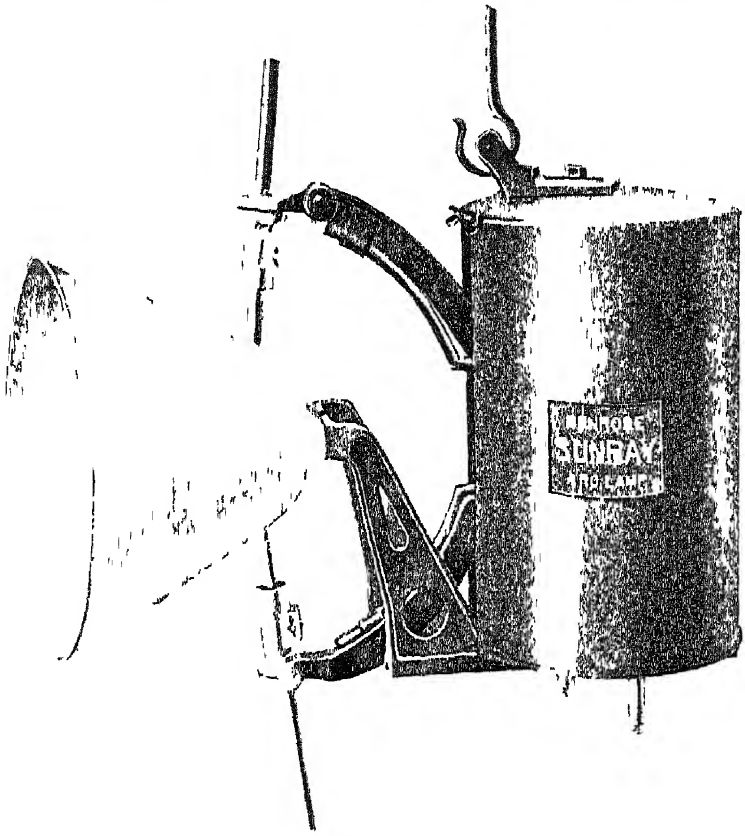

SUNRAY

Penrose
Squaring-up Machine.

For Colour Plates.

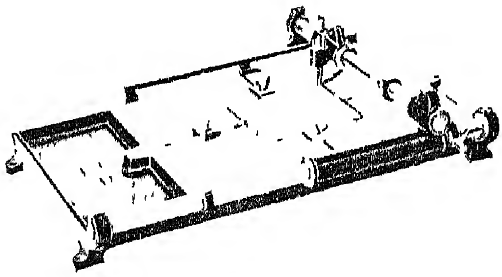
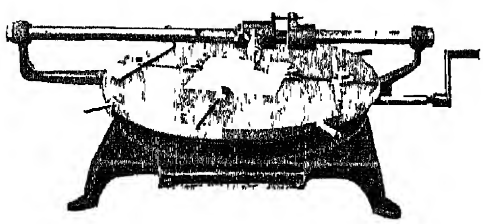


Photo-Engravers, who have to rule up colour plates, know the difficulty of getting the edges to coincide when printed The picture itself may be in perfect register, but the edges show unsightly over-lapping of the colours, spoiling the effect of the picture

This difficulty is entirely avoided by the machine above illustrated, which is now used by all the leading colour plate making firms and is highly approved Apart from the accuracy of the result, the work is done much more quickly than by the old methods

Penrose
"Megantic" Elliptograph. (Patent)

With Colour Registering Gauges.



This machine provides the same facilities for lining up colour plates, the only difference being that the Elliptograph is specially made for oval and circular plates Made in several sizes

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